A mining research contract report
January 1988

DEVELOPMENT OF A MONOREIL BRIDGE CONVEYOR SYSTEM

Contract J0333917
Goodman Conveyor Company Inc.

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR

50272-101

REPORT DOCUMENTATION PAGE	**1. REPORT NO.**	**2.**	**3. Recipient's Accession No.**

4. Title and Subtitle

Development of a Monorail Bridge Conveyor System

5. Report Date

November, 1987

6.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Goodman Conveyor Company, Inc.
P.O. Box 866
Belton, SC 29627

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(c) J033917

(G)

12. Sponsoring Organization Name and Address

Bureau of Mines
United States Department of the Interior

13. Type of Report & Period Covered

Final

14.

15. Supplementary Notes

Surface testing & evaluation of the Monorail Bridge Conveyor System; IC9146

16. Abstract (Limit: 200 words)

This report summarizes the results of the development and testing of a prototype monorail suspended bridge conveyor (MBC) system as a method of continuous haulage in underground mining applications. Included are the results of full scale, surface and underground testing of the complete MBC system. Conclusions drawn from these results, together with recommended modifications, supports the viability of the MBC system.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	**19. Security Class (This Report)**	**21. No. of Pages**
	20. Security Class (This Page)	**22. Price**

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

FOREWORD

This report was prepared by Goodman Conveyor Company, Inc. It represents a summary of work recently completed under a U.S. Bureau of Mines Contract No. J0333917. The contract was administrated under the technical direction of the Bureau of Mines with Mr. Robert J. Evans acting as the Technical Project Officer and Mr. Joseph A. Gilchrist as the Contract Administrator.

The author wishes to express a sincere appreciation to the U.S. Bureau of Mines and its staff for their support and cooperation on a program which in many ways had to cover new ground. A special thanks are to Robert J. Evans, William D. Mayercheck and Joseph L. Saliunas for their encouragements and help. Also, the author wishes to recognize the staff and personnel of Turris Coal Company for their efforts and enthusiasm in making possible the underground demonstration of the MBC.

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UNIT-OF-MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	lb/ft	pounds per foot
ft.lb	foot pound	min	minute
ft/min	foot per minute	pct	percent
h	hour	r/min	revolution per minute
hp	horsepower	s	second
Hz	hertz	st	short ton
in	inch	st/h	short ton per hour
in/ft	inch per foot	V ac	volt, alternating current
kW	kilowatt	V dc	volt, direct current
lb	pound	W	watt

DEVELOPMENT OF A MONORAIL BRIDGE CONVEYOR SYSTEM

By Guenter F. Lehmann[1]

ABSTRACT

This report summarizes the results of the development and testing of a concept for a monorail suspended bridge conveyor (MBC) system as a method for continuous haulage in underground mining applications. Included are the results of full scale, surface and underground testing of the complete MBC system. Conclusions drawn from these results, together with recommended modifications, supports the viability of the concept and the practicality of the MBC system.

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INTRODUCTION

Over the decades, the mining of coal has advanced from pick and shovel to mechanized (conventional) mining to today's continuous mining. The development of mining machinery, especially those machines at the mine working face, has outpaced the ability to move the coal safely as fast as can be mined. Today, this shortcoming is seriously effecting overall operating costs and the ultimate cost to the consumer. The shuttle car haulage system, a most commonly used form of moving the coal away from the face to the next stage of rail or belt haulage (approximately 250 to 500 feet), is inherently inefficient due to its cyclic operation. Thus, the efficiency of a continuous miner maybe reduced to as much as 50% of its capacity.

In the past, both the industry and the Bureau of Mines have pursued the development of a compatible continuous haulage system. A number of concepts evolved. To date none have proven to be fully effective and each suffers from certain drawbacks.

In 1979, the U.S. Bureau of Mines received U.S. patent (#4,157,757) for the basic concept of a monorail suspended continuous face haulage system, i.e. the monorail bridge conveyor (MBC). In brief, the system consists of a series of cascading belt conveyors or bridges, suspended off an inverted T-section monorail bolted to the mine roof. The concept incorporated many of the most successful features of past designs without some of their shortcomings. The development and proof of concept, including fabrication, was performed by the Goodman Conveyor Company Inc. (GCC) under a cost sharing program with the Bureau (Contract #JO333917).

During the course of the development, full scale sections of the system were exhibited and demonstrated in operational settings to obtain industry reaction and feedback. It was shown that the MBC as developed and tested, has the potential to substantially improve the movement of coal as a basis for increased productivity. The MBC offers a captive guidance system requiring only a single operator station. The system may be extended or shortened to meet conditions. The operation is not affected by bottom conditions as is the case with present haulage systems. Safety of operation, a prime consideration, is improved by eliminating the need for rubber-tired haulage equipment, trail cables and moving-vehicle accidents. The MBC is designed to work in all room-and-pillar operations such as mining rooms, entries, panels, pillar extractions and short-wall mining.

The author believes that the objective:

"To develop and test the concept of a monorail bridge conveyor continuous haulage system."

was accomplished. Although the program did not intend nor result in a finished commercial product, the results and experience gained have proven the validity of the concept.

BACKGROUND

Underground continuous haulage systems have been tried or employed in Europe and the United States since the mid 1950's. Commercially available systems can be grouped into three general categories: (1) crawler-mounted alternating series of mobile bridge carriers and piggyback bridge conveyors, (2) monorail suspended systems, and (3) noncascading systems. The crawler-mounted systems generally require an operator every 50 ft. and are limited to a total length of under 200 ft.

The only commercial monorail system available today has been installed in a U.S. trona mine and at several foreign locations. Although it has a unique continuous belt with no crossover points, it is relatively heavier and more expensive, and it is more difficult to change the system length in comparison with the MBC system, which can attain a length of more than 500 ft. with just a single operator.

The noncascading systems, which have been recently introduced and remain untested underground, are relatively more expensive and present more difficulties in changing the system length.

The program from its inception to conclusion consisted of four distinct phases i.e. design, fabrication, surface test and underground demonstration. The design and fabrication were performed at the facilities of the Goodman Conveyor Company, Inc. Surface testing was performed at the Pittsburgh Research Center of the Bureau of Mines, Pittsburgh, PA. The underground demonstrations were performed at the Turris Coal Company, Elkhard, IL under a separate letter of agreement between Turris Coal and the Bureau of Mines.

DESIGN CONSIDERATIONS

The MBC concept as imbodied in the U.S. patent (#4,157,757) consists of a series of overlapping and cascading conveyor bridges of 40 ft. length each, suspended of a roof-mounted monorail. Movement (tramming) is accomplished by wire rope and winches analogous to a cable car. Analysis of the concept confirmed its premise but did question certain critical aspects of the proposed design.

During a detailed design study, specific parameters were developed to assure a safe and workable system. Specifically, the study defined three points:

1. Conveyor bridge length. Since the MBC must function within a minimum envelop of 18 ft. wide and 4 ft. height of a room and pillar mine plan, the bridge length was established at 24 ft. The resulting configuration represents a weighted compromise between maneuverability, operating clearance, suspension loading and simplicity of the overall system.

2. Suspension system. The various elements of the suspension system are interactive at all times. Thus, their relationship is critical. Suspension point, pivot or hinge point and the impact point of coal being discharged onto the receiving belt, must be coincidental.

3. Tram system. The proposed method of rope and winch to move the MBC was shown to produce unacceptable high horizontal and lateral forces within the monorail suspension. Most importantly, the arrangement was considered a high safety risk.

   Similar high forces were expected when using a continuous miner or any other floor-operating motive power source. The use of individual tractors for each bridge effectively reduced those forces to a manageable level and offered a safe tramming system.

DESCRIPTION OF THE MBC SYSTEM

The MBC consists of a series of cascading belt-conveyor bridges suspended of a special roof-mounted monorail. As designed and tested, the MBC is a complete system including all mechanical, electrical and control components. It is a true continuous haulage system with the ability to follow the movements of a working continuous-miner while conveying coal up to 288 away to a secondary haulage system. The MBC system specifications are shown on Table 1.

The three types of MBC bridges or units (inby, intermediate, and outby) are shown in Figure 1. Each unit consists of a belt conveyor mounted on a rigid frame, monorail-suspension hardware, a monorail-mounted tram unit, and electric power and control components. All MBC units are totally monorail suspended except for the inby and outby units. The inby end of the inby unit is mounted on rubber tires, which are steered remotely. The outby end of the outby unit can be supported either by a dolly mounted on a rigid-belt structure or by the monorail directly over the section belt. See Table 1 for descriptions and various MBC components.

Conveyor Units

Individual conveyor units are fabricated from rectangular structural tubing, providing a lightweight and rigid frame. Conveyor units are 27 ft., 7 in. long overall, with an active length of 24 ft. Presently, 12 conveyor units are available for a system length of 288 ft.; however, with electrical modification, additional units can be added to provide increased system length. A plan view of a typical intermediate unit is shown in Figure 2. A 36-in-wide, 5/16-in-thick belt is supported on a conveyor unit with a maximum width of 7 ft. Catenary-type, 4-in-diam. carrier idlers are installed on a 25 troughing angle. A 1,750-r/min, 10 HP electric motor powers the belt on each unit. A 7:1 double-reduction gear-speed reducer is coupled to the head-drive roller to provide a constant 400-ft/min. belt speed, and 7-in-diam. crowned drive and idler rollers are used. The tail idler roller is mounted on an adjustable screw-type takeup. The belt has a rated capacity of 600 st/h. Compression-spring belt cleaners are mounted under the head roller of each unit.

TABLE 1 - MONORAIL BRIDGE CONVEYOR SPECIFICATIONS

(Prototype system: 12 conveyor units available for 288 ft. length; expandable to greater length)

System specifications:[1,2]		
Haulage rate, nominal	st/h.	600
Tram speed, constant	ft/min.	60
Electric power requirements, V ac:		
Main system		460
Control system		120
Power output, total (for 12 units), hp:		
Conveying		120
Tramming		20
Entry width, recommended minimum	ft.	14
Load, typical maximum on a suspension point	lb.	2,000
Working height, minimum, in:		
Without low-belt structure		48
With low-belt structure		54
Gradability, recommended maximum	pct.	6.5
Curved-track radius	ft.	24
Crosscut geometry[3]	°	60-90
Individual bridge specifications:		
Dimensions, ft:		
Length:		
Overall		27.6
Effective		24
Width, overall		7
Carrier idlers (on 25° angle), diameter	in.	4
Rollers, head and tail, diameter	in.	7
Belt width	in.	36
Belt speed, constant	ft/min.	400
Power output, hp:		
Tram drive motor		1.5
Conveyor motor		10
Weight (empty)	lb.	4,200

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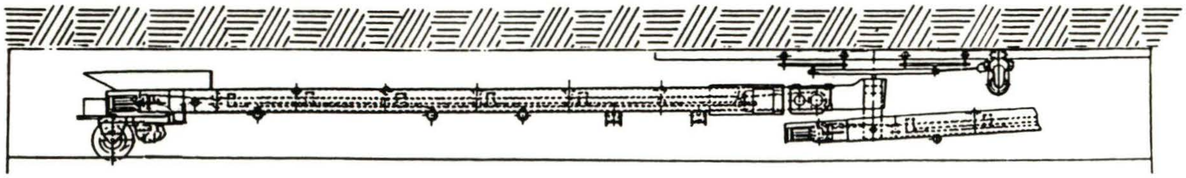
[1] Monorail track: 24 ft radius, designed for 60° crosscuts; available in 7- and 10- ft lengths; weight, 7 lb/ft; suspended on 4-ft centers.

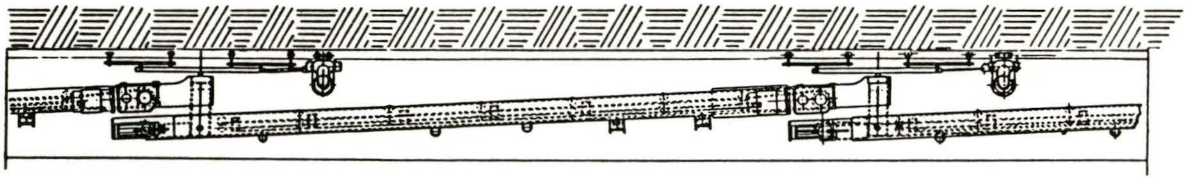
[2] Inby support: remotely steered rubber tires.

[3] 90° crosscut: Compound curve must be used with the stipulation that intersecting arc lengths must not exceed 30° to prevent interference.

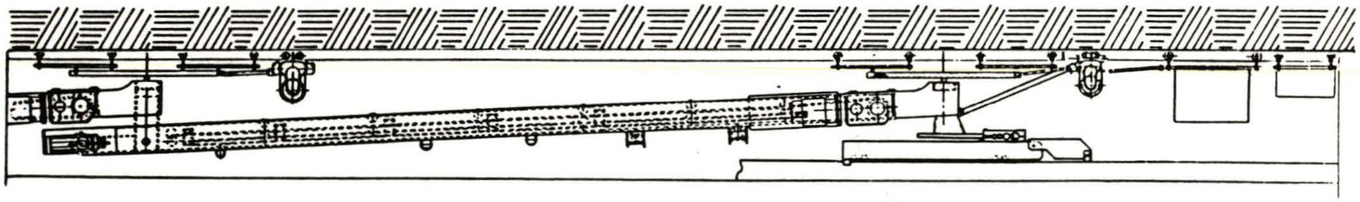
NOTE: All units can be controlled by single operator; helper optional. Safety features: Belt slip and sequence switches, disk brakes on each tram unit that engage automatically when tram power is shut off, emergency stop on each unit, pendant control from any unit, end-of-monorail stop on inby unit, and warning horn before belt startup.



Inby unit



Intermediate unit



Outby unit

FIGURE 1. — Three types of monorail bridge conveyor units.

Power and Control

The MBC is operated by 460-V ac, three-phase, 60 HZ electric power provided by a No. 2/0 trailing cable to the outby main breaker box. Transformers located in each motor control box supply 120-V ac, single-phase, 60 HZ power for the control system. The 10 HP, 440-V ac, single-speed conveyor motors and the 1½ HP, 440-V ac, single-speed, reversing tram motors have across-the-line starting. The motor control box on each unit is equipped with an emergency-stop pushbutton station that disengages the main circuit breaker.

The electrical system is modular in design with identical power and control wiring on all but the inby and outby units. Figure 3 shows a typical intermediate unit containing the motor control case and interconnecting cables common to all units. The inby unit has an additional control case (Fig. 4) that is required for the steering motor and headlight controls. The outby unit is connected to two additional control cases (Fig. 5): the main breaker case, which houses the main-system circuit breaker, and the master control case, which contains the emergency-stop controls for the entire system.

The MBC system employs automatic, sequential belt startup. When the conveyor is first activated, an audible warning signal is heard. After a brief period the signal stops, and the conveyors start in sequence beginning with the outby unit. Sequence switches allow each successive unit to start only after the preceding unit is running at full speed. Should a conveyor stop for any reason, all conveyors inby the defective unit will stop automatically. Each unit has a manual override that will operate the conveyor on that unit. This control is intended for maintenance and diagnostic use only.

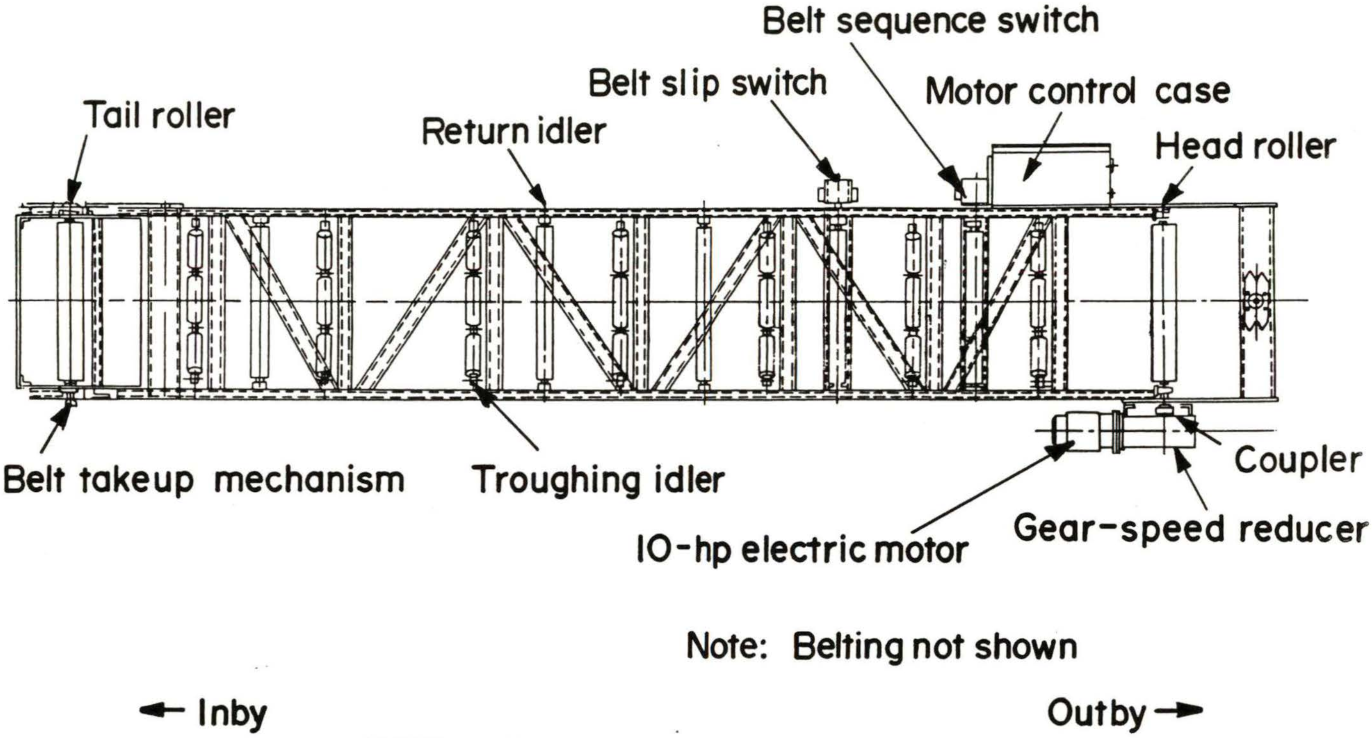


FIGURE 2. — Plan view of monorail bridge conveyor unit.

FIGURE 3. — Intermediate unit.

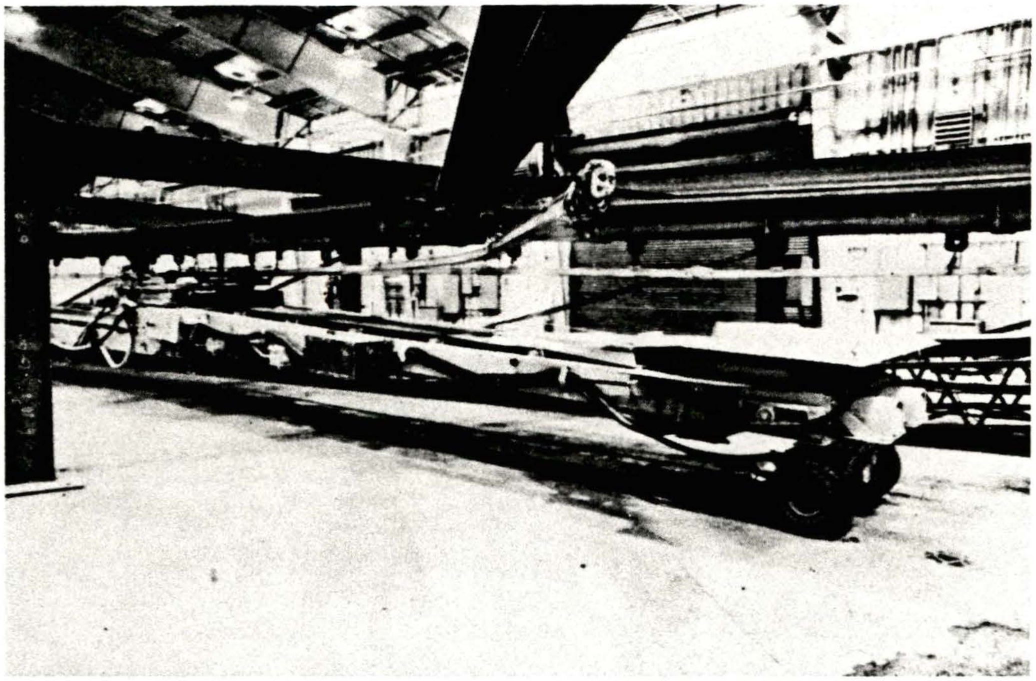


FIGURE 4. — Inby unit.

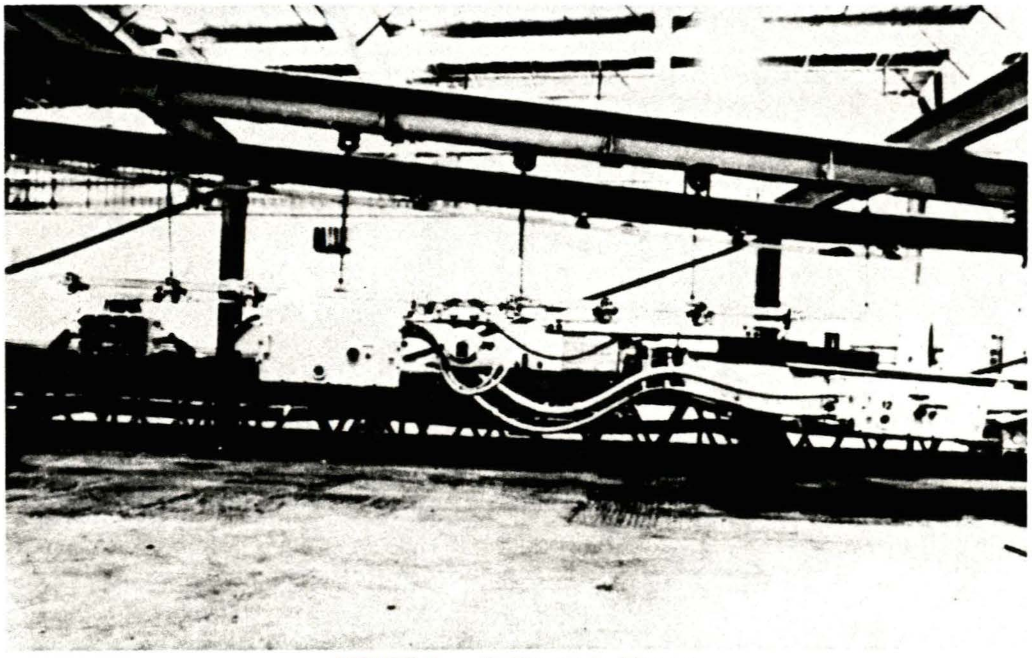


FIGURE 5. — Outby control boxes.

Controls for steering, tramming, and conveying are located on an umbilical pendant control. The pendant control (Fig. 6) may be connected to any unit in the system. This provides operator convenience and allows positioning to avoid blind or unsafe MBC operation locations. During face operations, the pendant control will typically be located on the inby unit, so the operator can best control the inby steering.

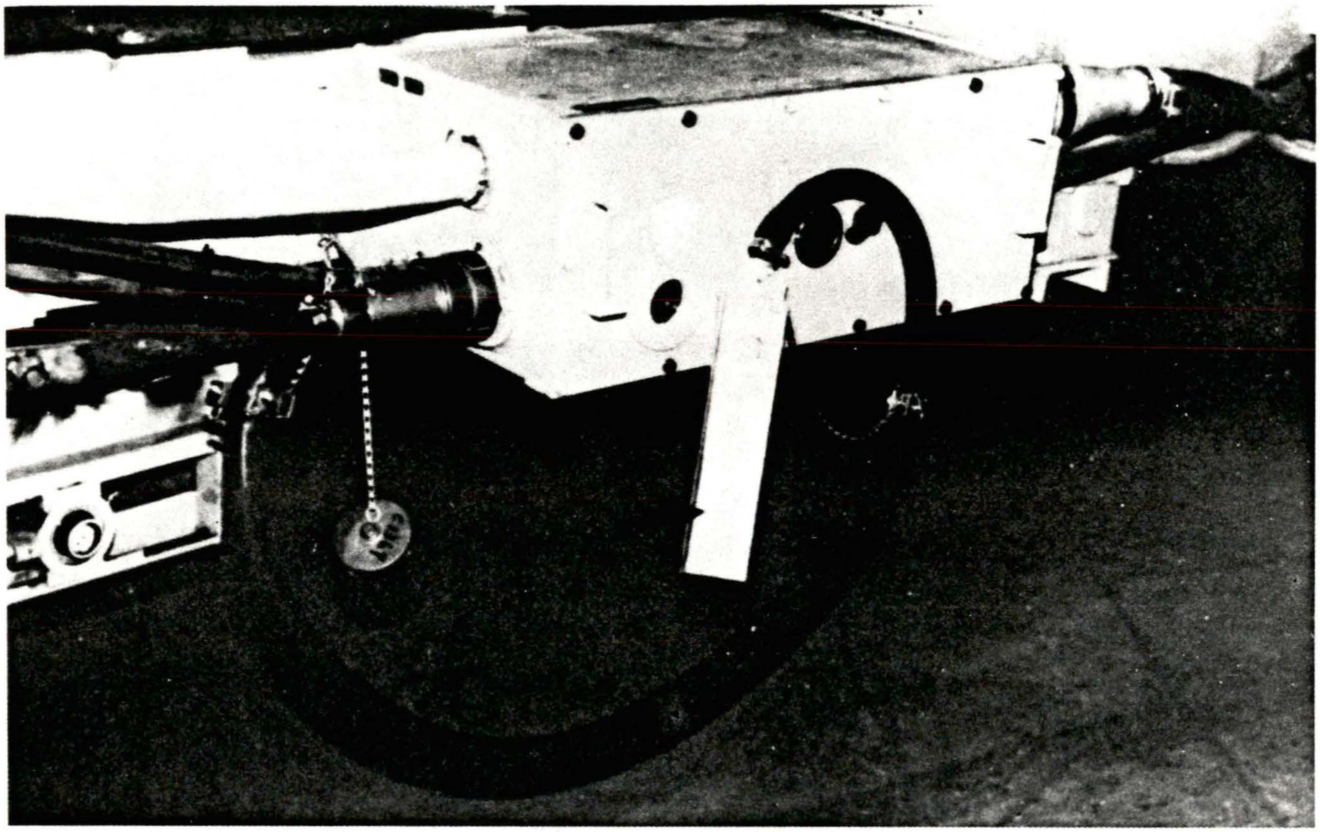


FIGURE 6. — Pendant control.

The MBC system can be trammed on the monorail track in both the inby and outby directions, with each tram motor equipped with an electric brake. The brake remains set when the machine is stationary. Upon activation of the tram control, the brake releases and sets again when the tram control is deactivated. If a brake becomes overheated, it can be manually released to prevent further heat buildup.

Should any unit develop a major malfunction requiring it to be removed from the system, all electrical connections can be disconnected at the plugs and receptacles that interconnect the units. The units are reconnected in the same manner.

Tramming and Support System

Both ends of each conveyor unit are supported by eight-wheel carrier assemblies that distribute the weight of each conveyor on the monorail tract. The carriers are designed to follow both vertical and horizontal curves in the monorail track without affecting conveyor suspension. A 1,100-r/min, 440-V ac, 1.5 HP traction motor is used for tramming each conveyor unit. The motor drives two friction wheels that are held against the underside of the monorail track. A 24:1 triple-reduction speed reducer is used to provide a constant tramming speed of 60 ft/min. Disk brakes on each tram motor automatically engage when the system is not being trammed.

A lightweight monorail track is used to suspend the MBC system. The inverted T-section track, made by Cleveland Tram-rail (Cleveland Crane and Engineering, Div. of McNeil Corp, Wickliffe, OH) weighs 7 lb/ft and comes in eight factory-available configurations, as illustrated in Figure 7. Straight rail is available in 14-, 10-, and 7-ft. lengths. Curved and combination rails in various lengths make 60 turnouts with a 24 ft. radius. Other lengths and configurations of monorail can be fabricated underground to suit particular mine conditions. A hydraulic rail bender is commercially available for field-fitting curves. Four bolts are used to join monorail track at overlapping splice plates. Both right- and left-hand manually operated monorail switches are available. Figure 8 shows two types of hardware that can be used to suspend monorail track. One type of suspension hardware uses a semirigid connection to suspend monorail track from roof plates attached to the mine roof with two roof bolts. Bevel-headed

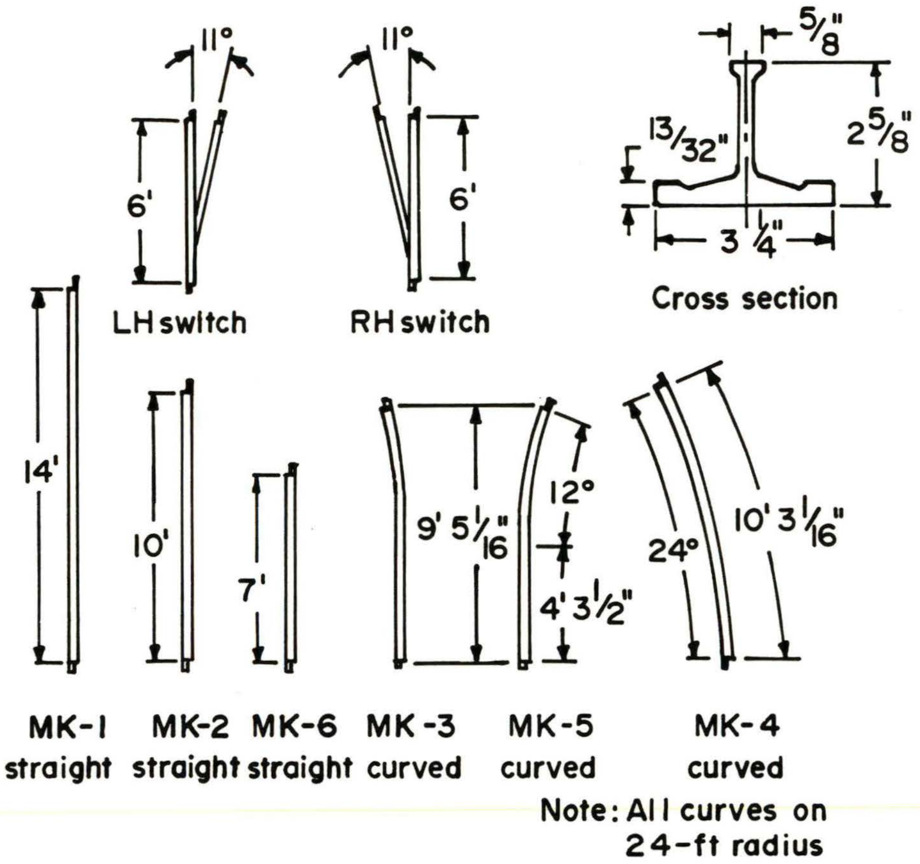


FIGURE 7. — Monorail T-section track configuration with designated identification numbers.

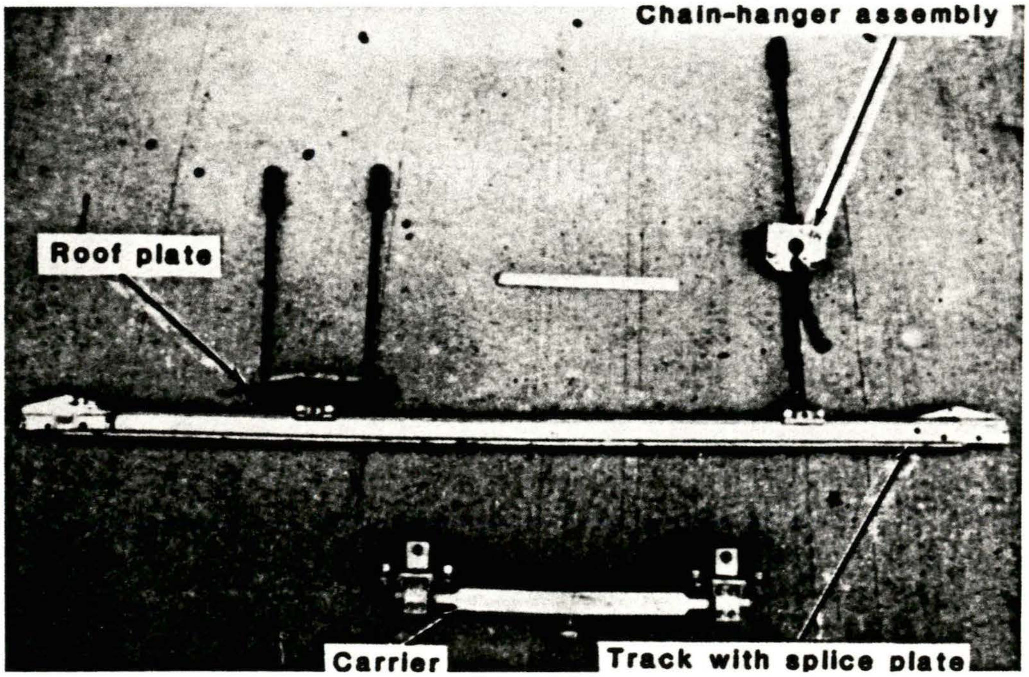


FIGURE 8. — Monorail hardware.

bolts seated in the roof plates are connected to the monorail track, allowing limited horizontal track movement. A second type of suspension hardware enables a nonrigid connection to suspend the monorail track using a chain-hanger bracket attached to the mine roof with one roof bolt. Varying lengths of chain connect the monorail track to the chain-hanger bracket, allowing horizontal and vertical movement of the monorail track.

Inby Support

The inby end of the MBC system is supported by two 9-in-wide rubber tires installed on 38-in centers. The wheels are powered by a 1.5 HP electric motor at 60-ft/min constant tram speed. The tram motor and gear-speed reducer are mounted behind the rubber wheels. A separate 440-V ac, 1.5 HP electric motor and ball thread are used to steer the inby wheel carriage. The steering motor is controlled from the pendant control.

The height of the inby conveyor unit over the rubber tires is 32 in. The height was increased to 40 in. with the addition of a low-profile hopper.

Outby Support

In low-coal applications, the monorail track can be offset from the panel belt, and the outby end of the MBC can be supported by a dolly mounted on rigid belt structure (Fig. 9) or on a chain panline. The dolly ensures transfer onto the panel belt without spillage. In higher coal, the outby end of the MBC could be suspended from monorail installed directly over the panel belt.

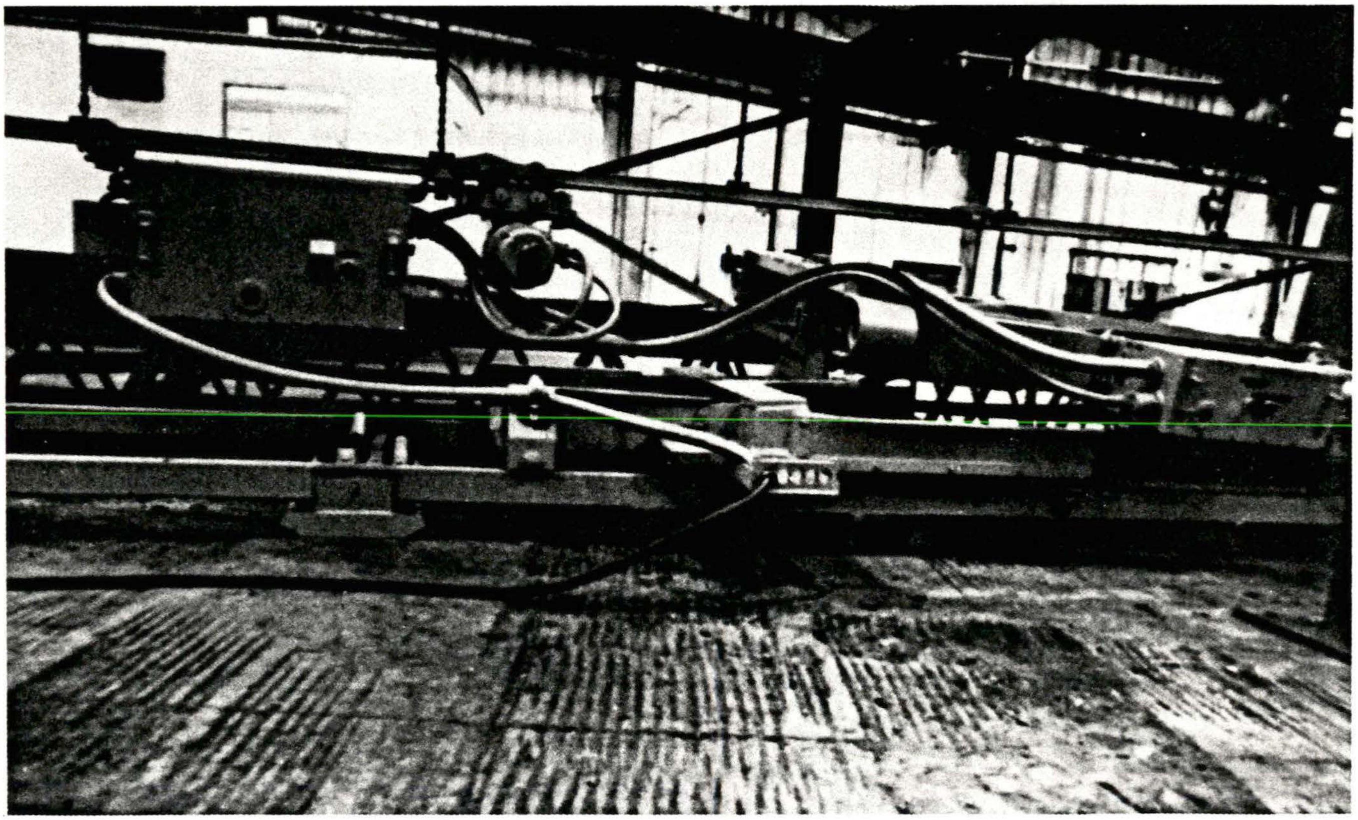


FIGURE 9. — Outby support with dolly.

SURFACE TESTING

As a proof of concept program, the MBC needed to be tested in a surface installation prior to the actual installation in an underground mine operation. Thus, to closely simulate those conditions within practical limits, three of the twelve complete conveyor units (1 inby unit, 1 intermediate unit, 1 outby unit) including all necessary hardware were tested in a specially designed test rig installation erected within the facilities of the Bureau of Mines at Bruceton, PA. The surface tests were conducted with the purpose of evaluating the concept, to verify and measure the MBC haulage capability, maneuverability, power consumption and reliability. Both rigid- and chain-suspended monorail track installations were tested. Numerous modifications were made to several MBC subsystems to correct problem areas and or improve performance identified during the surface testing.

Test Rig Installation

A steel structure was designed and constructed to function as a false mine roof from which the monorail could be suspended (Fig. 10). The test rig enabled MBC testing on straight and radius tracks, through switches, and on a 6½-pct grade. It consisted of nine arches supporting underhung beams. Two separate 140-ft. lengths of monorail track were supported from these beams. The two monorail track sections were parallel to each other and offset by 8 ft. Two 80-ft. portions of both monorail tracks were installed on a 6½-pct slope. A single, 60-ft. arc length of the 24-ft-radius monorail track was connected to the main track by a switch. This basic test rig was used to support both rigidly bolted and chain-suspended monorail tracks. For initial test sequences, the monorail track was bolted to the underhung beams.

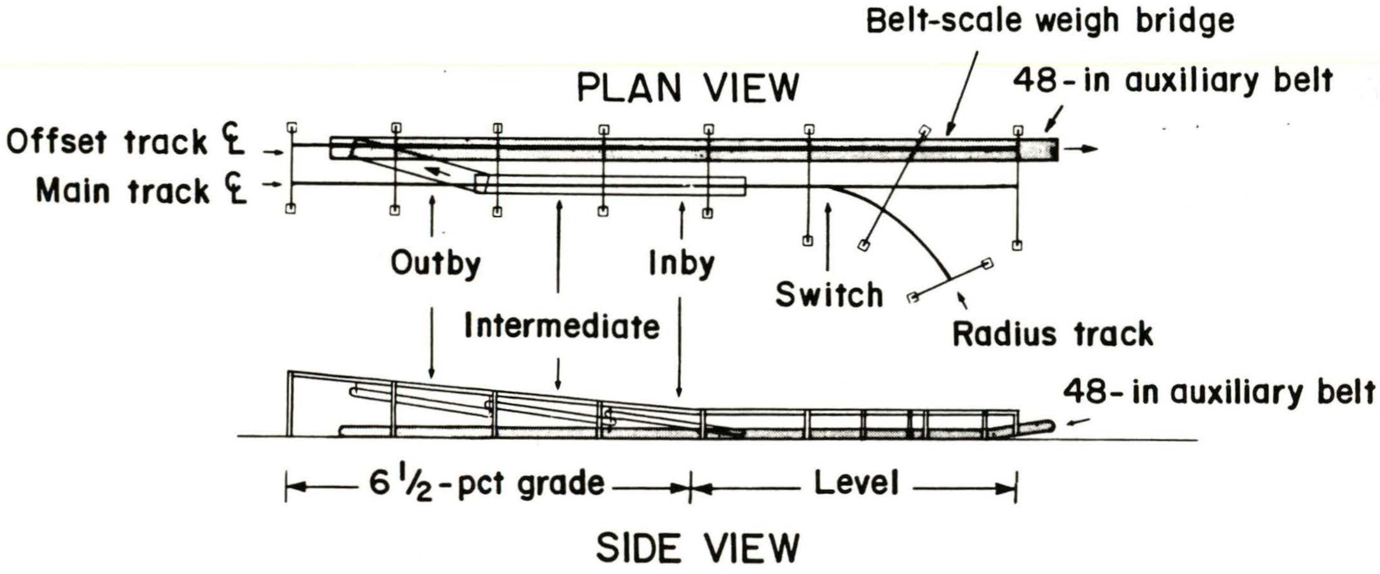


FIGURE 10. — Surface test rig.

A 40 ft. long 48″ conventional belt conveyor operating at 625 ft/min was installed under one of the monorail tracks. This belt conveyor established a closed-loop for coal conveying tests. A beltscale weigh bridge was installed in the belt conveyor to measure the MBC haulage rate. Figure 11 shows the MBC units installed in the test rig.

Operational Test

After installation of the MBC system and hardware into the test rig, tramming and conveying tests were conducted to verify proper alignment, freedom of movement and the function of all motions. The 6½ pct. grade and the monorail switch were trammed in both directions without difficulties.

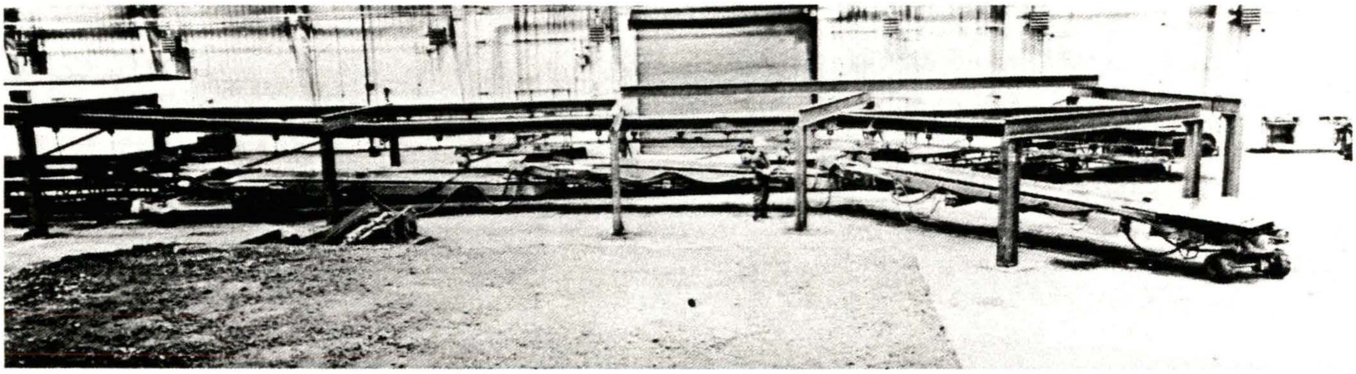


FIGURE 11. — Monorail bridge conveyor system in test rig.

These tests indicated the need for certain modification prior to the commencement of full scale coal conveying. Weights were added to each bridge structure to counterbalance the weight of control and power cables. Rubber aprons were added to all dump points to prevent spillage while tramming through the rail switch into a turn.

Initial loading tests were conducted with all MBC units in straight alignment. The MBC was intermittently loaded at the inby hopper by a slow discharge of coal from the 500-lb. capacity bucket of a skid loader. It was then loaded for several minutes by an 8-st-capacity shuttle car dumping into the inby hopper. No major operational problems were encountered with the MBC during these tests, and it was able to convey coal at normal haulage rates.

During the initial checkout, a decision was made to install an electric steering control for the inby rubber wheels. The original manual steering wheel, located beside the inby hopper, was awkward to operate and potentially unsafe. New gearing, a mounting bracket, an electric motor, and a control switch were installed.

Power Consumption

Power-consumption tests were conducted to determine overall system electrical characteristics and to specifically investigate if the number of tram motors could be decreased without affecting system performance. Each MBC unit is equipped with one monorail tram drive. An additional rubber-wheel tram drive is used on the inby unit. The rubber-wheeled tram drive on the inby unit, located several inches off the ground, was determined to be in an undesirable location because of potential water damage and ground clearance problems. Therefore, it was desirable to eliminate this motor, but only if doing so would not overload the remaining motors. For the power-consumption tests, the number and location of the tram motors were varied for both loaded and unloaded conveyors, and for upgrade and downgrade gradients. The test variables and results are listed in Table 2.

For all tests except G, H, I and J, the original roller chain drive on the inby rubber wheels was connected. (This original roller chain drive was later replaced with a sealed, gear-speed-reducer driver). For the tests using three rail motors (E, F, G, H, I and J), the rubber-wheeled tram dreive was electrically disconnected. For the tests using only two rail motors (S, T, V, W), only the monorail tram drives on the inby and outby units were operated, and the inby rubber-wheeled tram drive and intermediate unit monorail tram drive were electrically disconnected. For the tests using four rail motors (X, Y, Z and AA), an additional tram motor was installed on the monorail immediately outby the inby unit tram motor. These two tram motors were connected by a short drawbar.

For test A through O, the average power consumption for both level and 6½-pct-grade track was determined. The power consumption for a 20-ft. length of track, at the start of upgrade tests and at the end of downgrade tests (Fig. 12), was used for the level, kW on level track column of Table 2. The power consumption for a 10-ft. length of track, at the end of the upgrade tests and at the beginning of the downgrade test, was used for the "Grade, av kW" (6½-pct) column of Table 2. Between these points, the grade traveled by each tram motor varied.

Brake Test

The tram drive of each bridge conveyor unit is equipped with an electric, operated multi-disc brake. Purpose of the brakes are to hold the MBC in position on grades up to 6½-pct in the event of a power failure or a normal

TABLE 2 — MONORAIL BRIDGE CONVEYOR POWER CONSUMPTION

Test	Motor Used		Level,[1] av kW	Grade, av kW	Peak kW	Design Max kW
	Rail	Wheel				
			UPGRADE GRADIENT			
Conveyors unloaded:						
A	3	1	2.8	4.1	5.0	4.5
E	3	0	2.0	3.5	3.8	3.4
G	[2]3	0	1.8	3.4	3.6	3.4
S	2	0	(3)	3.4	3.6	2.2
Z	4	0	(3)	4.3	4.8	4.5
Conveyors loaded:						
O	3	1	2.9	4.7	5.8	4.5
J	[2]3	0	2.0	4.0	4.8	3.4
W	3	0	(3)	4.0	4.2	2.2
Y	4	0	(3)	4.7	5.8	4.5
			DOWNGRADE GRADIENT			
Conveyors unloaded:						
B	3	1	2.8	1.4	3.4	4.5
F	3	1	1.9	.7	2.2	3.4
H	[2]3	0	1.7	.5	1.8	3.4
T	2	0	(3)	.5	2.3	2.2
AA	4	0	(2)	1.3	2.9	4.5
Conveyors loaded:						
I	[2]3	1	2.9	.4	2.2	3.4
N	3	1	2.9	1.3	3.1	4.5
V	2	0	(3)	.4	3.1	2.2
X	4	0	(3)	1.1	3.1	4.5

[1] For "upgrade gradient", the units were traveling from right to left, and for "downgrade gradient", the units were traveling from left to right on the level portion of track.

[2] Rubber-wheeled tram drive electrically and mechanically disconnected for these trials.

[3] Test configurations did not permit power readings on level track sections.

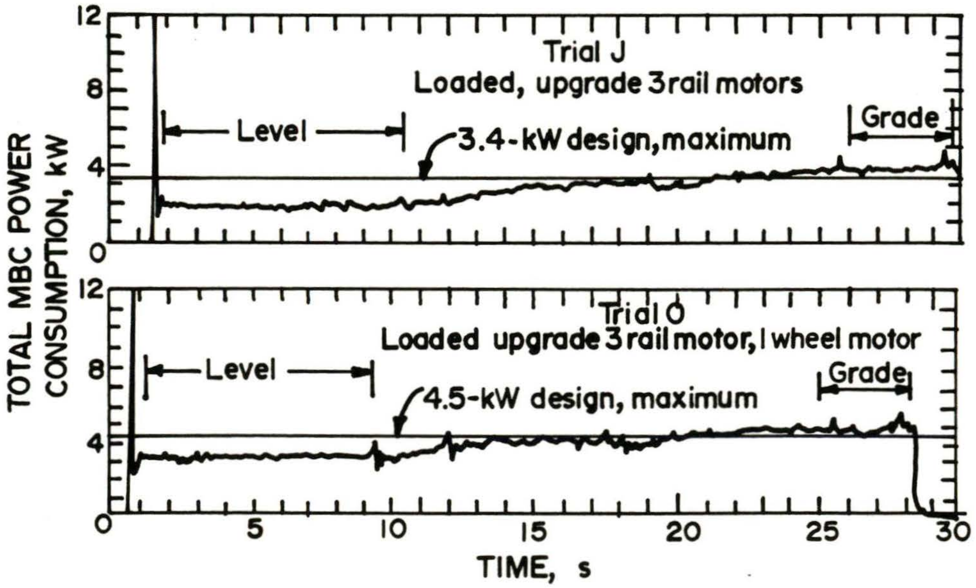


FIGURE 12. — Typical power-consumption plots.

power-off condition such as parking. To test the brakes, the loaded MBC was trammed into the 6½-pct grade test section, and the brake on the inby unit de-activated, next the brakes on the inby and intermediate unit were de-activated. During both of these tests, all three bridge units remained stationary thus verifying that the MBC can be safely operated on grades up to 6½-pct even if several brakes are inoperable.

Haulage Rate

The objective of the haulage-rate tests was to determine the maximum haulage capacity of the MBC and to investigate spillage sources. To measure the instantaneous and total weights of coal moved by the MBC system, an electronic belt-scale system installed on the 48-in-wide auxiliary belt was used. To obtain a high haulage rate, the MBC system was installed in a closed-loop configuration (Fig. 13). The MBC system was located in the radius portion of the test rig. The outby unit dumped coal onto the auxiliary belt, which dumped onto a 30-ft-long, 36-in-wide flat belt. The flat belt then dumped coal into a shuttle car, which dumped back into the inby MBC unit hopper. Run-of-mine (ROM) bituminous coal was added to the system by loading coal into the shuttle car.

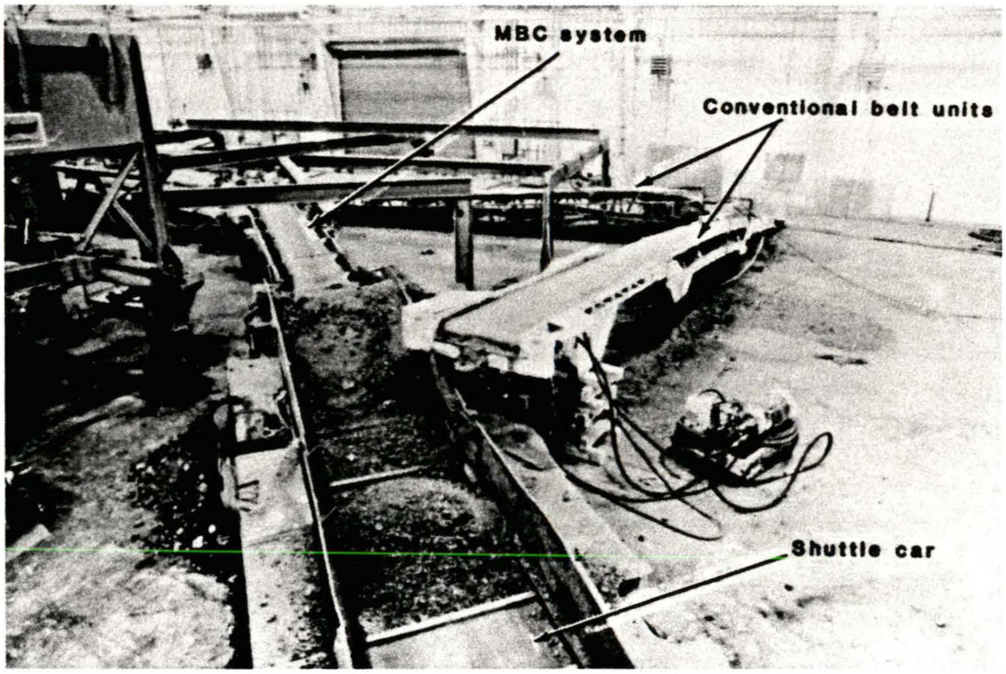


FIGURE 13. — Closed-loop test configuration.

With the MBC located in the radius portion of the test rig the inby and intermediate MBC units were at a 43 degree angle to each other. This worst-case configuration occurred where the two conveyors intersected at the center of the 60-degree arc of the radius track section.

Figure 14 shows the strip-chart readout for the haulage-rate trial. An average of 450 st/h of coal was handled without experiencing problems with the MBC system. The decreasing haulage rate, after coal addition was stopped, was due to spillage at the shuttle car. Spillage at the MBC transfer points was negligible.

A second series of tests were conducted to establish the maximum haulage rate of the MBC system. Belt-motor power consumption and haulage rate were monitored. Coal was added to the closed-loop circuit until failure of the flat auxiliary belt precluded additional loading. The peak instantaneous loading rate during this trial was 600

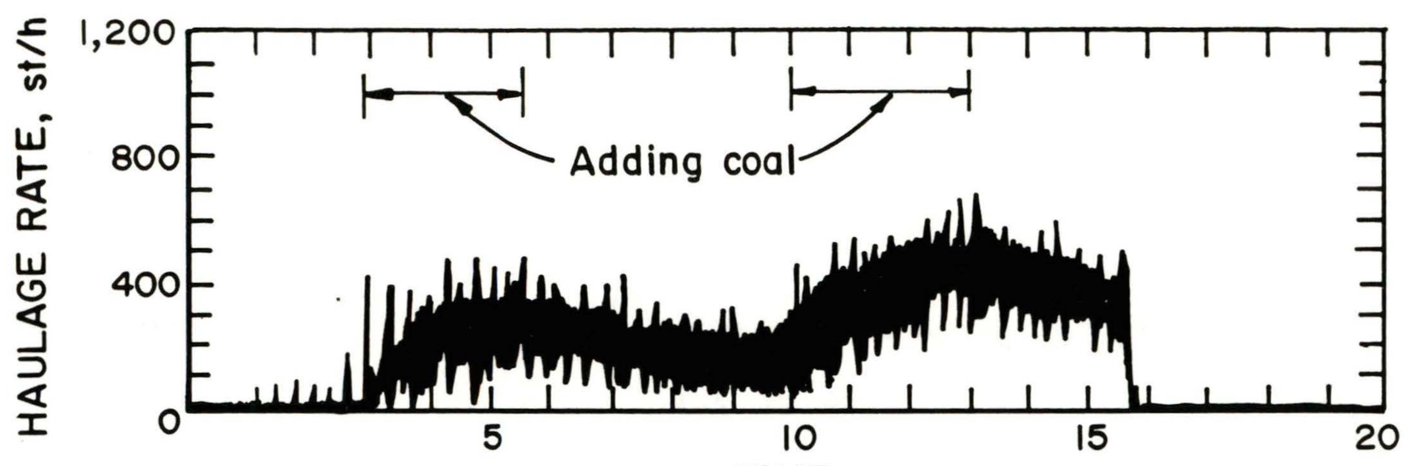


FIGURE 14. — Haulage-rate graph.

st/h (Fig. 15). No problems were observed with the MBC system during peak loading rates. All belts remained in alignment, and spillage at the transfer points was minimal. The maximum observed conveyor-motor power consumption was 16.8 kW for three motors. These tests verified that the MBC is capable of haulage at its design specification of 600 st/h.

FIGURE 15. — Haulage rate and power plots during maximum haulage-rate trial.

Continuous-Miner Loading Test

The objective of the test was to verify the ability of the MBC to simultaneously tram and receive coal from the discharge boom of a continuous miner, as would be done underground. A Joy 16CM continuous miner was used to load directly into the hopper of the inby unit (Fig. 16). The miner had a 24-in-wide and 8-in-deep chain conveyor area. A 15-st pile of wetted ROM bituminous coal was placed in front of the miner. The miner was positioned inby the MBC system, which was located in the radius portion of the test rig. The outby MBC unit discharged onto the 48-in auxiliary belt. A 10-st capacity shuttle car was used to receive coal discharged from the auxiliary belt.

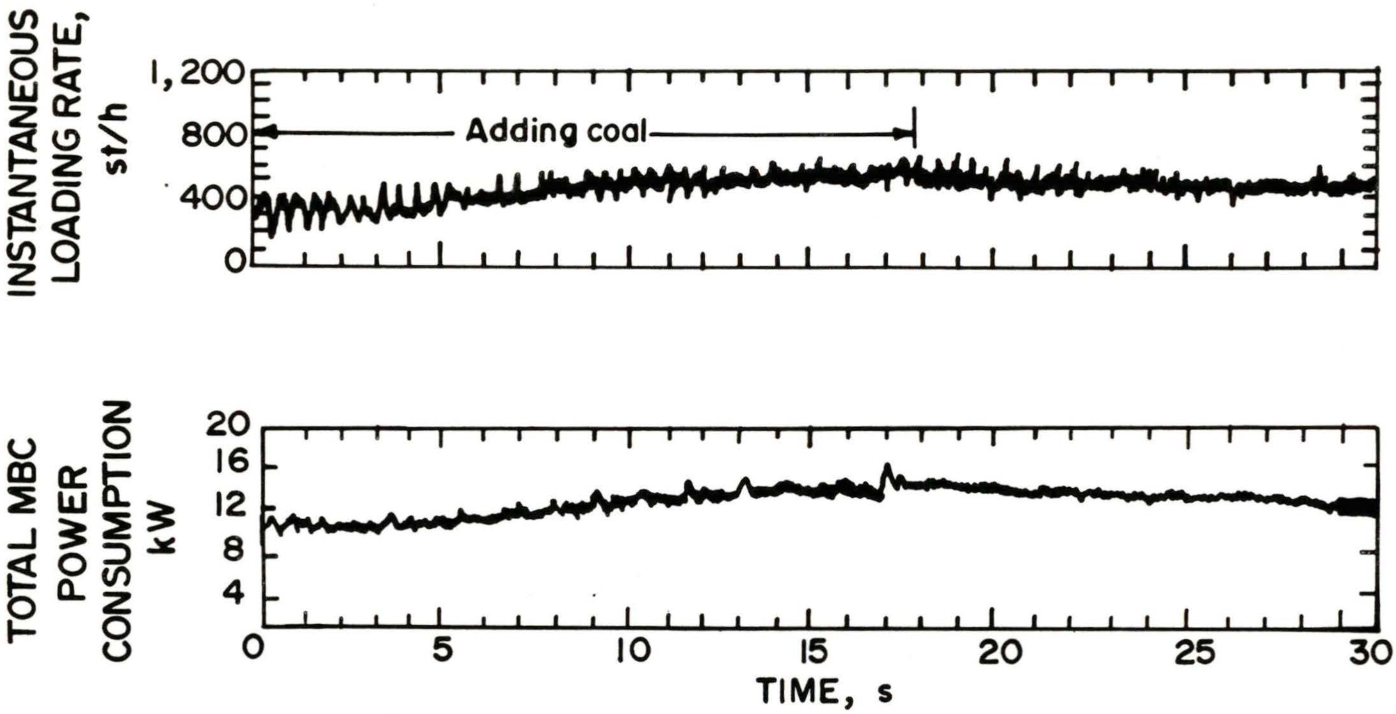


FIGURE 16. — Continuous miner loading directly into monorail bridge conveyor.

For each trial, the instantaneous loading-rate instrumentation was started, the miner was trammed into the coal pile, and the miner operator directed the miner tail boom toward the MBC hopper. The MBC operator, located beside the inby MBC motor control case, trammed and steered the MBC system as required to locate the MBC hopper under the discharge from the continuous miner. The miner advanced approximately 15 ft. into the coal pile until the pile was eliminated. After each test, the MBC and miner was backed up, and the shuttle car dumped the coal in front of the continuous miner. For several tests, the miner was maneuvered to simulate coal face cleanup operations. Total tonnage for each test was determined from the belt-scale totalizer. The total tonnage loaded and maximum instantaneous MBC haulage rate for each test were:

Test A — 10.1 st loaded at a maximum rate of 690 st/h.
Test B — 8.2 st loaded at a maximum rate of 720 st/h.
Test C — 12.9 st at a maximum rate of 720 st/h.
Test D — 10.0 st loaded at a maximum rate of 630 st/h.
Test E — 7.6 st loaded at a maximum rate of 600 st/h.

The miner operator had no problems keeping the inby hopper of the MBC under the miner tail boom as the miner trammed into the coal pile. The MBC operator was also able to maneuver behind the mine during face cleanup operations. This test sequence verified the ability of the MBC to simultaneously convey coal and tram.

Reliability

To determine the reliability of the conveyor portion of the MBC system, the MBC was installed in a stationary closed-loop configuration. ROM bituminous coal was added to the circuit by slow discharges from a 500-lb. capacity loader bucket into the hopper of the inby unit. Coal continued to be added until the belt-scale output showed an average rate of 500 st/h. Recharges of coal were occasionally necessary when spillage losses in the circuit caused the rate to fall to 300 st/h. All coal was wetted prior to loading for dust control.

For the entire test, the instantaneous loading rate, the 48-in auxiliary belt speed, the belt-scale load-cell output, and the total MBC power consumption were plotted on a strip-chart recorder. Water was applied to the underside of each MBC belt every hour to control dust generation.

During the reliability trial, the MBC conveyors loaded 2,141 st of ROM coal during 5.7 h, for an average loading rate of 375 st/h. Loading-rate peaks of 600 st/h occurred several times during the trial.

Figure 17 shows two 36-min, instantaneous loading rate, and the total MBC power-consumption traces. The upper trace occurred at 3.1 h into the trial. After coal addition stopped, the average laoding rate was approximately 390 st/h. The average power consumption for the same time was approximately 11 kW or approximately 15 hp; i.e., half the rated motor capacity of 30 hp. The scattered peaks and variations in power consumption were probably due to very fast openings and closings of one or more of the belt-slip centrifugal switches, which in turn shut the conveyor belt motors on and off. MBC belt-speed variations were not noticed during power-consumption variations.

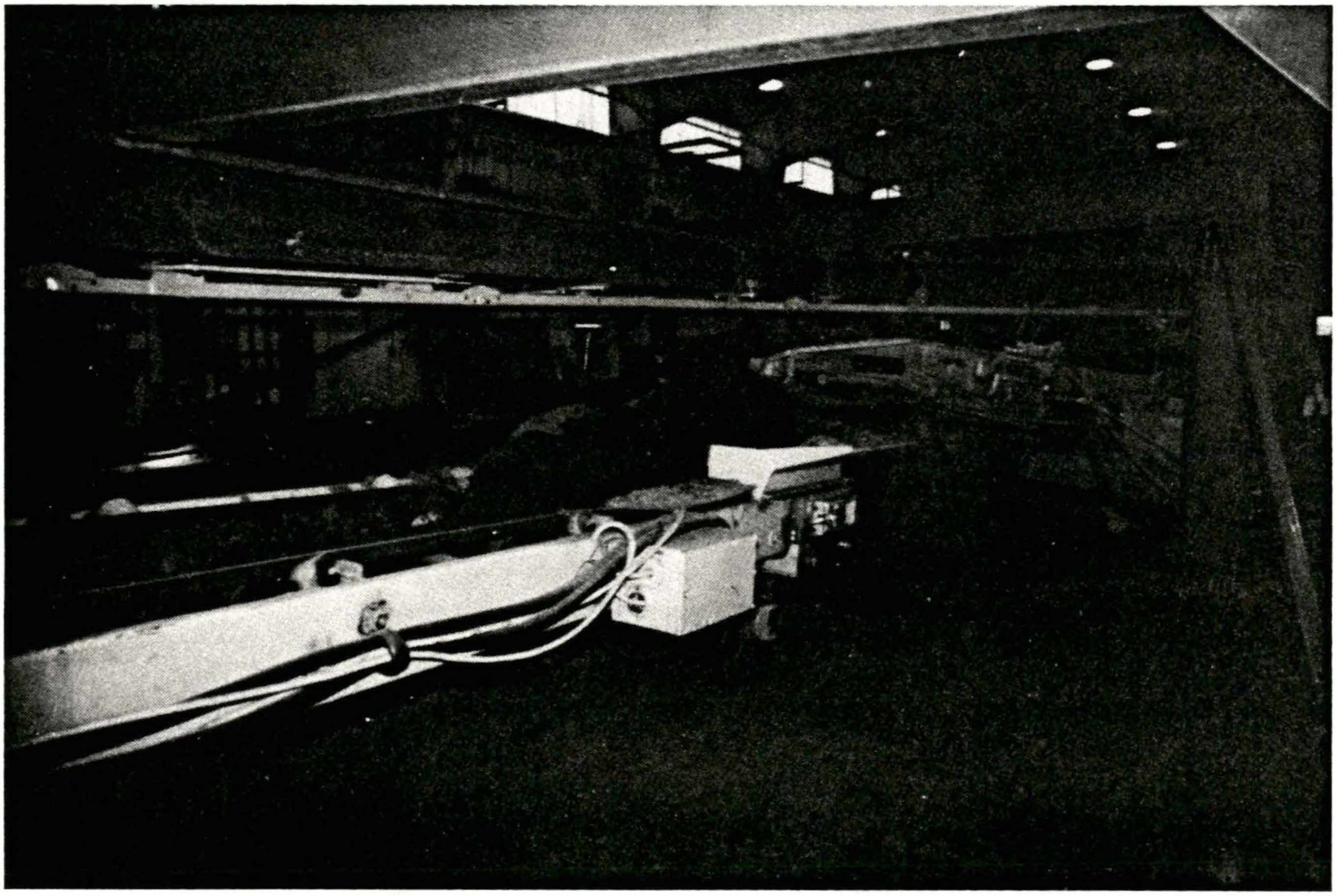


FIGURE 17. — Loading rate and power consumption during reliability trial.

The bottom trace was acquired at 4.1 h into the test when the system was being restarted. After coal addition stopped, the average loading rate was 480 st/h. The average power consumption for the same time was 12.5 kW. Observed variations in both total MBC power consumption and loading rate were dampened with time because of more equal distribution of coal in the circuit. Midway through the bottom trace, a belt-slip switch was opened while the left was being cleaned.

The reliability trial was terminated at 5.7 h into the test because of a spill at the intermediate discharge point that was caused by excessive coal flow, which buckled the hoop-type deflector. Coal was being added to the system at the time, and the haulage rate exceeded 600 st/h. This spill contributed greatly to the total spillage amount that had accumulated at the inby discharge point. After the test, spillage at both the inby and intermediate transfer points was raised. There was 700 lb. of spillage under the inby transfer point, and 4,650 lb. of spillage under the intermediate transfer point. Figure 18 shows the spillage under the inby transfer point.

FIGURE 18. — Spillage under the inby intermediate transfer unit.

Prior to the spill, it was observed that spillage under the intermediate transfer point was twice the amount under the inby transfer point, or approximately 1,400 lb. Based on the lower prespill assumed value, 2,100 lb. of spillage occurred during the trial, and the total amount of coal loaded was 2,141 st. Spillage rate during this trial can then be computed as 0.05 pct. of throughput. It is likely that the spillage rate might be higher during in-mine operation, since the system would be occasionally tramming during conveying operations. During the entire reliability trial, the inby and intermediate conveyors were at a 5 degree angle to each other, and the intermediate and outby conveyors were at 20 degree angles.

Compatibility Test With Low-Belt Structure

To insure smooth coal transfer onto the section belt, the outby unit end of the MBC may be a) suspended from the monorail installed directly over the section belt or b) attached to a dolly riding on the low belt structure. To demonstrate the compatibility with a commercially available low-belt structure, a 32 ft. section of 42" wide structure and dolly were installed under the chain-suspended section of the monorail (Fig. 9).

No problems were observed during repeated tramming of the entire MBC and dolly in both directions over the low belt structure. Although not tested, the material transfer capacity of the dolly-mounted outby unit is not expected to represent any problems.

Suspension of Monorail Track by Chain Hangers

Two methods of suspending the monorail track off the mine roof were tested; a) rigid attachment of the track to roof plates anchored to the mine roof, b) chain-suspend the track from chain-brackets anchored to the mine roof analogous to a conventional chain-suspended rope belt conveyor. Roof plates minimize the required headroom, but are difficult to adjust and require two roof bolts. Chain hangers allow easy height adjustment and require only one roof-bolt, but dictate a greater headroom. To determine if the MBC system can tram on a freely suspended track, a 50 ft. section of the track in the test rig was suspended from chain hangers using 1/4 in. high-strength alloy steel chain and modified hardware (Fig. 19). The chain hangers were bolted to the test-rig on 4′-0 center, recommended maximum spacing (Fig. 20).

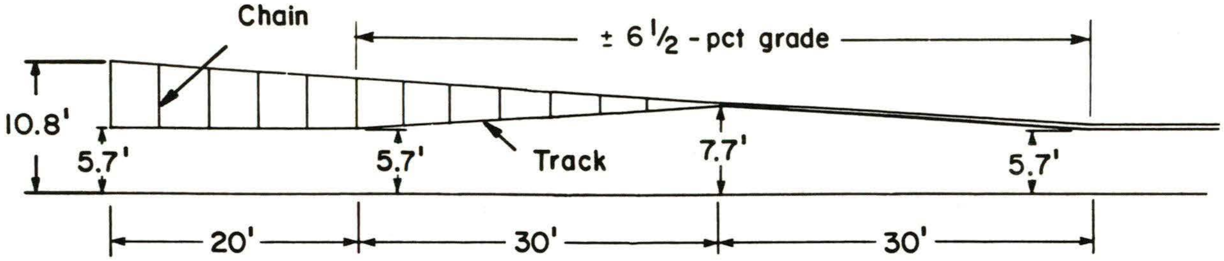


FIGURE 19. — Profile of chain-suspended monorail track.

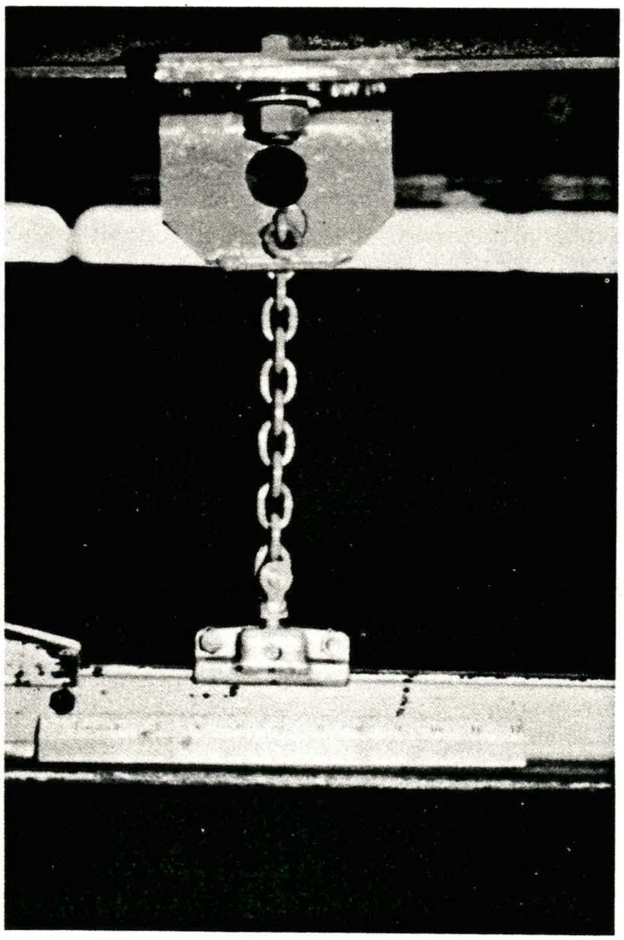


FIGURE 20. — Chain hanger arrangement.

With the outby end of the outby MBC unit mounted on a low-belt dolly as described earlier, the MBC was repeatedly trammed in both directions changing from rigid to chain suspended track sections. The eight-wheel carrier assemblies negotiated a 13-pct change in grade over a 3 ft. distance while traversing between rigid and chain suspend track. No problems were experienced with either MBC or track stability.

The chain suspension has shown to be a workable alternative to rigid suspension. Primary application would be in roof-fall areas, high or undulating mine roofs, etc.

Summary of Surface Test

Surface testing verified that the MBC system properly performs its design functions and is worthy of an in-mine trial. As expected, numerous modifications were made to the MBC system to either correct problems, improve performance or meet MSHA standards. Specific findings of the surface test program are summarized below.

- Tram-motor power consumption was measured for various tram-motor configurations.
- The braking system is more than adequate, as one functioning brake unit held three loaded MBC units on a 6½ pct grade.
- The ability to haul the design capacity of 600 st/h was verified.
- The MBC was capable of being loaded by a continuous miner. A maximum haulage rate of 720 st/h was measured during the miner loading trials.
- During a reliability trial, the MBC system loaded 2,141 st of coal in 5.7 h with only one minor coupler failure.
- The MBC was trammed with the outby end supported by a dolly mounted on a low-belt structure.
- The MBC was able to tram with monorail suspended from roof plates and chain hangers.
- The MBC is compatible with a hooper-feeder, which provides surge capacity and lump-breaking capability inby the MBC.

UNDERGROUND DEMONSTRATIONS

On completion of the surface test and the incorporation of certain modifications, the complete MBC system (12 units) was installed in a working mine section of the Turris Coal Company, Elkhart, Illinois. The underground demonstrations were conducted with the purpose of evaluating the MBC concept within a normal production schedule, to evaluate the degree of difficulties in the installation of the monorails tracks and to obtain preliminary production data. All work related to the underground demonstration was provided by Turris Coal Company under the direction of the Bureau of Mines with technical support from Goodman Conveyor Company.

Installation

The Turris Coal Company uses conventional mining to produce coal from the Springfield-Harrisburg Seam #5, with an average seam thickness of 54″. The room and pillar mining plan provides for entry heights of 8 ft. down to 6 ft. in certain areas. Mine roof conditions were not as stable as desirable, as was subsequently proven by numerous roof falls. The initial positioning and installation of the monorail track represented a lesser problem than had been expected. Both rigid and chain-suspension were used for the track installation. All twelve (12) MBC units were installed to function initially as an extendable belt (Fig. 21 & Fig. 22). The inby unit was loaded from a mobile hopper feeder-breaker (HFB) which in turn was loaded with shuttle cars. The outby unit straddled a section belt using a chute attachment for coal transfer (Fig. 23). The MBC system was started manually (no sequential control) and after satisfactory checkout of all functions, some coal was transferred. The feed rate of the HFB was adjusted to match the MBC.

A number of modifications, resulting from installation problems and design up-dates, were incorporated prior to full scale production runs. These modifications include the installation of a water-spray dust suppression system at all transfer point.

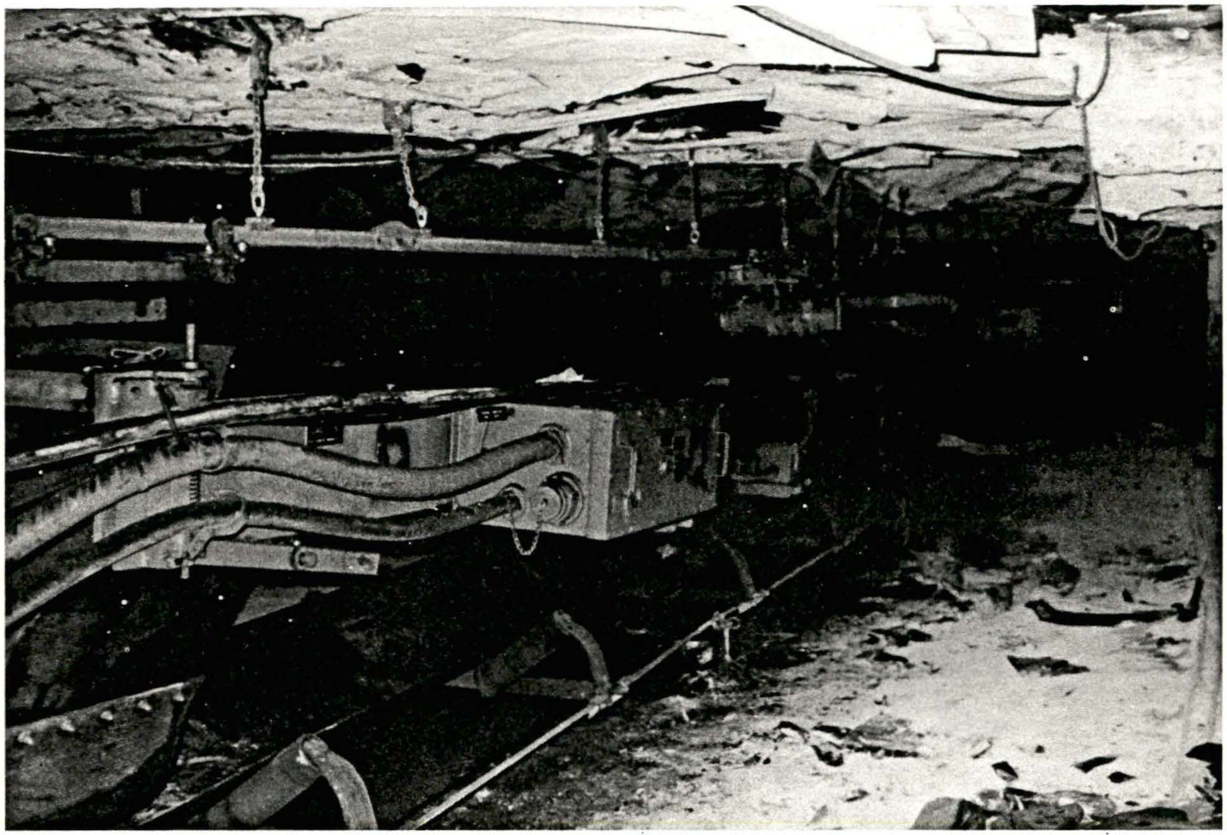


FIGURE 21. — MBC installation, left side.

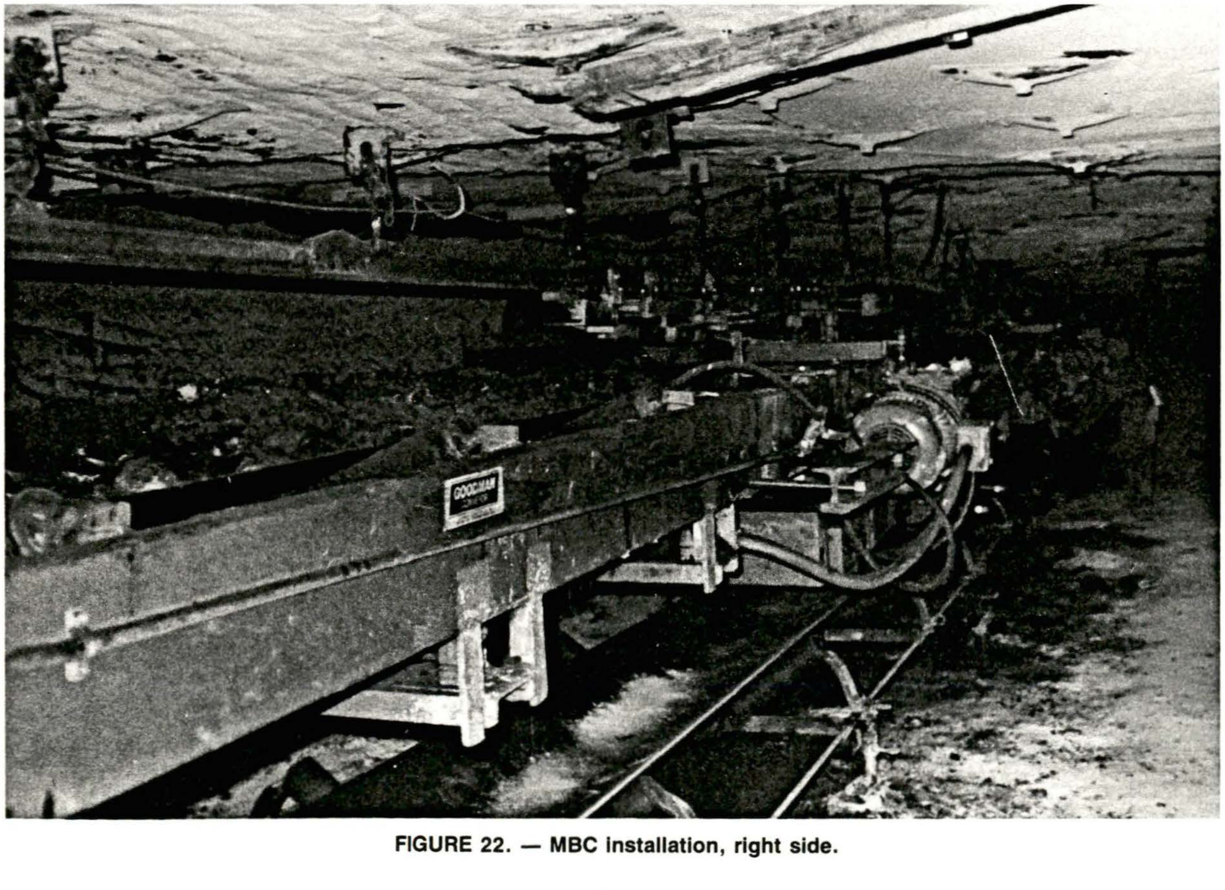


FIGURE 22. — MBC installation, right side.

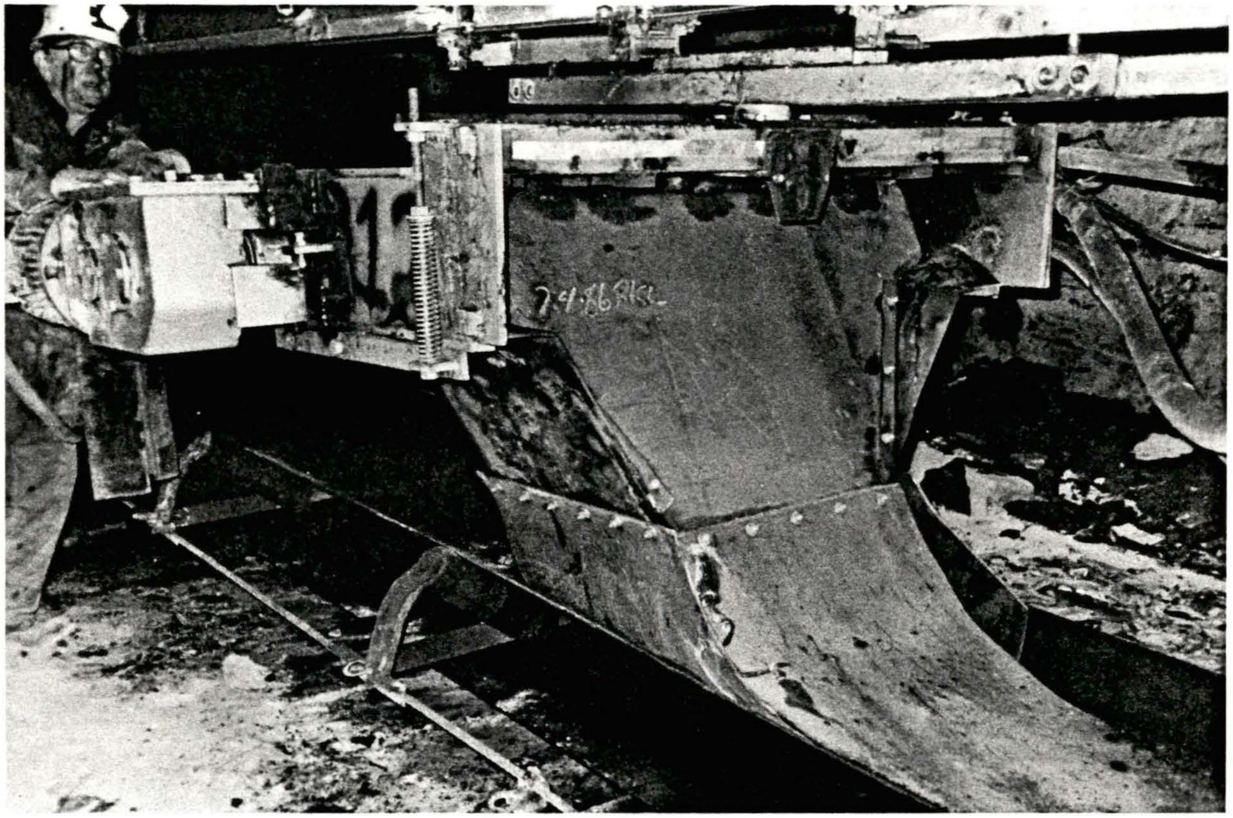


FIGURE 23. — Outby Discharge to Section Bolt.

Production

As installed, the MBC system was utilized for a period of 12 weeks primarily as an extendable conveyor within a production section. During that time, the MBC demonstrated a system availability averaging 88.1 pct. (Table 3).

TABLE 3 — AVAILABILITY

		MONTH	
TOTAL DELAYS/AVAILABILITY	**1**	**2**	**3**
MBC Maint + Oper Delay (Min)	380	983	280
MBC Maint + Oper Delay (%)	12.7	10.2	23.3
HFB Maint + Oper Delay (Min)	210	222	0
HFB Maint + Oper Delay (%)	7.0	2.3	0.0
System Total Delays (Min)	590	1205	280
System Total Delays (%)	19.7	12.6	23.3
MBC Availability (%)	87.3	89.8	76.7
HFB Availability (%)	93.0	97.7	100.0
System Availability (%)	80.3	87.4	76.7
Times moved to spare unit, or took system out of line due to MBC/HFB problems	4	1	2

The operation of the MBC was considerably restricted, thus the recording of production data over extended periods were not possible. Factors such as unfamiliarity with a new system and roof control efforts contributed much to the delays between actual usage. Table 4 shows the mine log recording productivity of the MBC in comparison with different mining methods. The data is not conclusive due to the extended delays between actual usage. For example, conventional haulage such as with shuttle cars, are less effected in operations by roof control problems. It must also be pointed out that during these tests, the MBC's prime characteristic namely the flexibility to follow a continuous miner and move coal directly to the section belt, were not adequately evaluated to allow a real comparison. However haulage rates measured over a period of hours were comparable to those recorded during the surface test.

TABLE 4 — PRODUCTIVITY

		MONTH			
TEST		**1**	**2**	**3**	**4**
Production Shifts (10 Hr. Shifts)		27	36	32	35
Total ROM Tons		16574	21440	22203	29642
Productivity, ROM Tons/Unit Shift		614	596	694	847
Mining Method					
1 Full Cont. Haulage)	Shifts				
	ROM Tons				
	Productivity				
2 Extendable Belt)	Shifts				
	ROM Tons				
	Productivity				
3 Conv. Haulage w/MBC) (Test)	Shifts	5	16	2	
	ROM Tons	429	7888	420	
	Productivity	86	488	210	
4 Conv. Haulage, No MBC)	Shifts	22	20	30	35
	ROM Tons	16145	13362	21783	29642
	Productivity	734	668	726	847
5 Other)	Shifts				
	ROM Tons				
	Productivity				

Operation

Tramming through track switches did not represent any problem. As had been shown during the surface test, the stability of the MBC system is dependent on the rigidness of the monorail track suspension. Using chains fastened to roof plates and positioned off-center at irregular spacing will restrain any sway induced from the ground movement of the inby unit. Installation of the monorail, eventhough it was not planned as an integral part of a working mine section, has shown to represent no greater problems than any other roof supported systems such as stationary belt conveyors. If the use of an MBC is made part of the mining plan, the original roof bolting operation using a planned pattern, can substantially reduce the cost of the track installation.

Single operator control of the MBC system was demonstrated as being realistic and safe. Eventhough the MBC was a new and unfamiliar concept without operational experience or how best to utilize in an overall production cycle, the simplicity and advantages of the MBC system were readily understood.

Summary of Underground Demonstration

As expected, and eventhough limited in time, the underground demonstration did answer many questions. To continue operation with the present design configuration however would contribute little to advance the MBC system. These tests have shown the need to modify the design beyond what field modifications could accomplish. Identified modifications, in particular those which address the material transfer between the bridges, the steering mechanism, the pulley design, leveling of the conveyors and the enlargement of the electrical system to accept more control and interface points, will require extensive changes to the major components of the MBC.

The monorail components of the MBC were designed to meet a very restrictive 48″ operation height. Thus the components are special and costly. A relaxation in operating height can substantially reduce the overall cost of the MBC by using off-the-shelf rail and tram components.

A re-evaluation of weight distribution within the active portion of the MBC will result in a more stable operation. Installation and handling would benefit directly.

The tests tend to indicate that an MBC system designed to meet a specific mine plan would offer greater operational success than a single design to fit all.

RECOMMENDED MODIFICATIONS

- **Monorail Tram Drive Suspension System**
  The overall height of MBC has a strong impact on the overall cost. Because of the custom design feature of the present monorail components, modifications must include a new tram system using standard parts, track, wheels, switches and drives. Motor and brake require MSHA certification.

- **Pulley Design**
  The original pulley design has a single end-disc welded into the tube. New design must have two end discs. To aid in belt training, the pulleys must have neoprene lagging added to help keep from sliding on pulley face.

- **Material Transfer Between Bridges**
  The transfer of material from one conveyor to another must be addressed. The spillage and belt training problem can be solved, if the coal will stay centered on the belts. The only way to do this is have a discharge chute at each transfer point designed in such a manner to keep the coal centered. The chute will be fastened rigidly to the discharge frame with angle guide to direct coal to chute. To allow clearance for the chute to pivot when the MBC is turning, the suspension frame must be redesigned to allow the chute to pivot, but will keep the moving coal centered on the conveyor belt.

- **Idler**
  An increased angle for the troughing idlers will help keep coal centered and will cut down on spillage. The troughing angle on idlers before the surface test was 20 degrees. It was changed to 25 degrees on all idlers except the first idler at tail pulley, and the last idler before discharge pulley.

- **Steering Mechanism**
  The only problem experienced with the steering mechanism occurred when the discharge boom from the HFB hit the inby unit. This caused one pillow block to fail and bending of the threaded steering rod.

  Modifications must consider larger components in pillow blocks and adjustment rods, greater clearance between wheels and frame and dust shield. A careful analysis of positioning must be included to determine effective radius of turn.

- **Leveling of Conveyors**
  Off-side location of the electrical cables is what makes the MBC lean to the control side of the frame. More balanced mounting location of cables, or alternate cables to opposite side of bridge conveyors is a must.

- **Dust Control**
  A water spray suppression system must be incorporated at all transition points.

- **Electrical System**
  Minimum changes to be made are:
    - Add indicator lights to control boxes to identify specific problem.
    - Add extra cable glands to all electrical enclosures.
    - Use standard MSHA approved control boxes.
    - Incorporate a communication system to talk from inby to outby unit.
    - Add electrical devices to monitor blocked discharge or transfer points.
    - Add provision to shut down MBC from side opposite of controls.
    - Increase systems capacity to accept additional conveyor bridges.

MINING PLANS

Based upon observations made during surface testing and the underground demonstration, the following mine requirements are suggested:

- The minimum working height of the MBC is 48 in. The minimum working height increases to 54 in. if the outby end of the MBC is supported by a 6-in. high low-belt structure (Figs. 24-25). Additional working clearance would ease cleanup under the MBC.

- Maximum gradability of the system is 6.5 pct without excessive tram motor wear. Greater grades can be negotiated at the expense of decreased tram-motor life.

- A minimum entry width of 14 ft is possible if 60 degree crosscuts are used and intersection corners are rounded; however, a wider entry is desirable to allow a walkway at all points on the clearance (right) side of the system.

- The MBC was designed for 60 degree crosscuts using the 24-ft radius monorail track, however, crosscuts of 90 degrees can be negotiated using a compound curve. In any turnout configuration, the angle between MBC units must be less than 34 degrees to prevent unit-frame interference with each other. An advantage of 60 degree crosscuts is that spillage between units will be minimized because potential spillage at transfer points increases as the angle between units increases. Figure 26 shows track installation plans for both 60 degree and 90 degree crosscuts.

- Supporting the MBC system should not be a problem because the eight-wheel carriers distribute conveyor weight over a 6-ft length of monorail track, which results in a typical load on each suspension point of less than 1 st. Although not tested, resin bolts are recommended over mechanical bolts to better withstand tramming-induced vibration.

  The MBC can be used for room-and-pillar mining (Figs. 27-29), longwall development (Fig. 30), or shortwall mining (Fig. 31). For room-and-pillar mine plans, the monorail track does not have to be installed in all mine entries. As illustrated in Figure 27, the monorail track would typically be installed over or beside the panel belt in the center entry and in each crosscut. The combined length of the inby MBC unit and the continuous miner enables mining in entries that do not have monorail track installed. The hopper of the inby MBC unit can be up to 20 ft. from the last point of monorail suspension. Assuming that a typical continuous miner is 35 ft. long, the continuous miner cutterhead can be up to 55 ft. from the last point of monorail installation (Fig. 32). Various cut plans are possible, depending on local conditions.

- A potential application of the MBC system would be in longwall panel development. As shown in Figure 30, the 288-ft MBC system would be of sufficient length to advance two crosscuts of a three-entry heading, thereby potentially reducing longwall-panel development time.

  An alternate use of the MBC system would be to provide continuous haulage capability for shortwall mining sections. Shortwall mining has the potential to provide productivity advantages of longwall mining without high capital costs. A major impediment to more shortwall application is the lack of a continuous haulage system. As shown in Figure 31, the MBC connects the continuous miner to the panel-belt conveyor with the monorail track bolted to mine roof in the headgate entry. In the face area, the monorail is supported underneath chocks with the provision that the lightweight monorail track could be manually connected after the chocks are advanced.

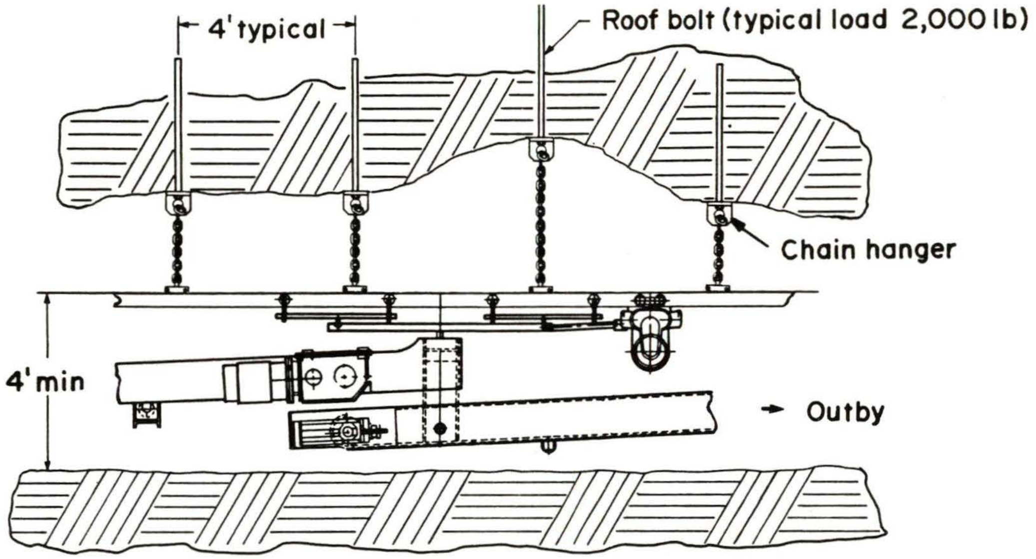


FIGURE 24. — Monorail installation with chain hangers.

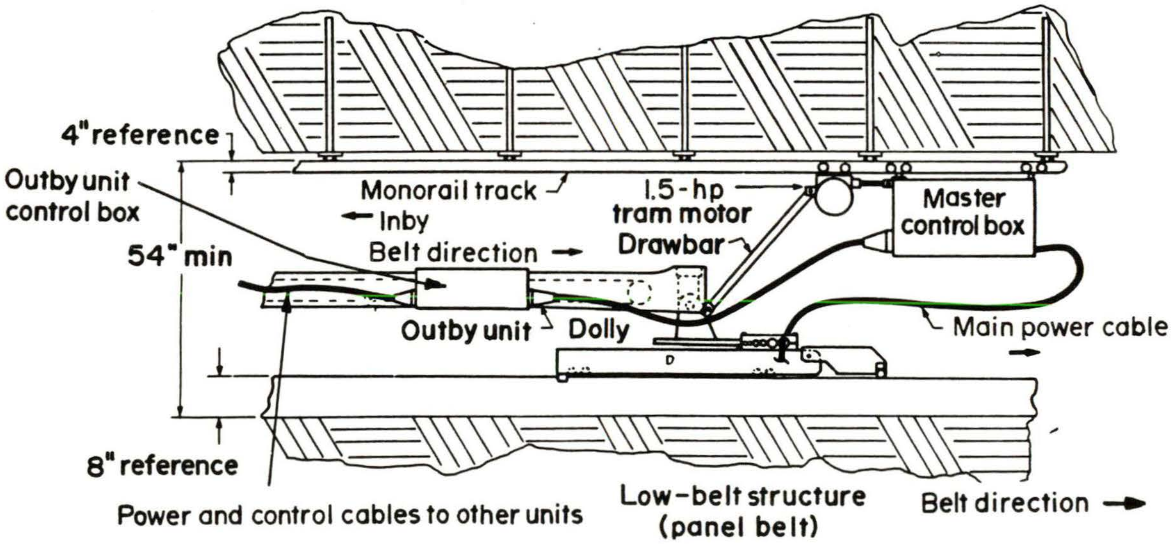
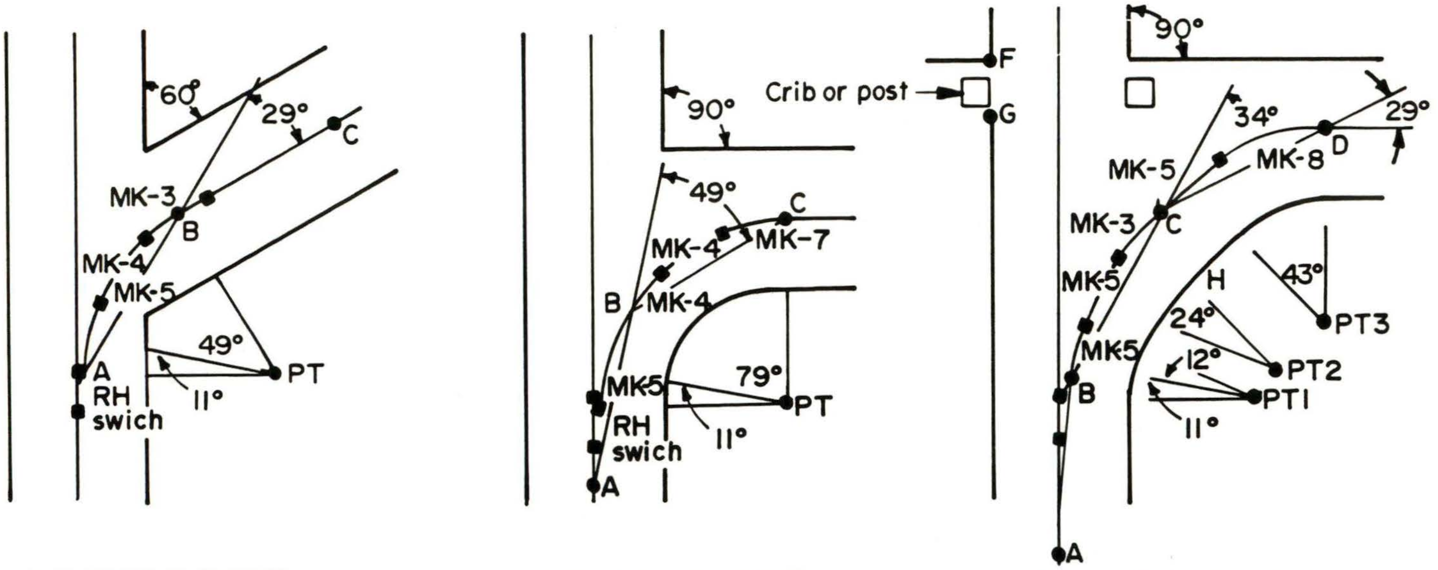


FIGURE 25. — Monorail installation with roof plates over low-belt structure.



60° SIMPLE CURVE
System can be used;
29° angle between $\overline{AB}$ and $\overline{BC}$
is <40°

90° SIMPLE CURVE
System cannot be used;
49° angle between $\overline{AB}$ and
$\overline{BC}$ is > 40°

90° COMPOUND CURVE
System can be used;
34° angle between $\overline{BC}$ and $\overline{CD}$
is <40°.
However, 2 x $\overline{FH}$=2 x 39ft=78ft.
This is too wide. Mine would require
extra roof support so that 2 x $\overline{GH}$
≤70 ft.

NOTES:

Maximum angle between units is 40°.
Only RH turnouts are shown.
Angle of switches, 11°.
Arc of track sections: MK-3 and MK-5, 12°; MK-4, 24°; MK-7, 19°; and MK-8, 31°. (MK-7 and MK-8 track not available at time of tests.)
All track curves on 24-ft radiurs.
All track is shown centered in 18-ft entry.

KEY

■	Splice plate
MK-5	Track designation
$\overline{AB}$	Represent units (each 24-ft long)
PT	Point of tangency

FIGURE 26. — Monorail bridge conveyor track turnout plans.

- If oversize material (over 12 in) is regularly encountered during the mining cycle, a crusher should be used inby the MBC system to avoid clogging MBC transfer points. The previously described HFB with optional bolter removed, can perform that task. Additional advantages of using the HFB between the continuous miner and the MBC are that (1) surge capacity is provided; (2) an outby feeder breaker can be eliminated; and (3) extra system reach is provided. As seen in Figure 33, the continuous miner cutterhead can be up to 80 ft from the last point of monorail installation. If the MBC is used with the HFB, the two systems could be connected (Fig. 34).
- One operator is required for the entire MBC system, although it may be desirable to temporarily station a helper at the outby transfer point to the panel belt to assure proper transfer. Mine personnel should be instructed to stay on the clearance side of the system where the emergency shutoff switches are located.

In a continuous haulage mode with the MBC positioned directly behind the continuous miner, the MBC operator would control tramming and steering to follow the miner. The pendant remote control will allow the operator to be positioned to avoid pinch points and to view loading operations. Various hopper capacities and profiles could be installed on the inby end of the system to maximize the target area for the miner operator. Depending upon the mine plan, the miner power cable could be carried by the MBC.

Two methods of monorail track installation are possible. If lack of head room is a problem, the monorail track can be directly attached to the roof, using roof plates (Fig. 25). Another method, using chain hangers, is shown in Figure 24. Roof plates require two roof bolts for installation, while chain hangers require one. Chain hangers

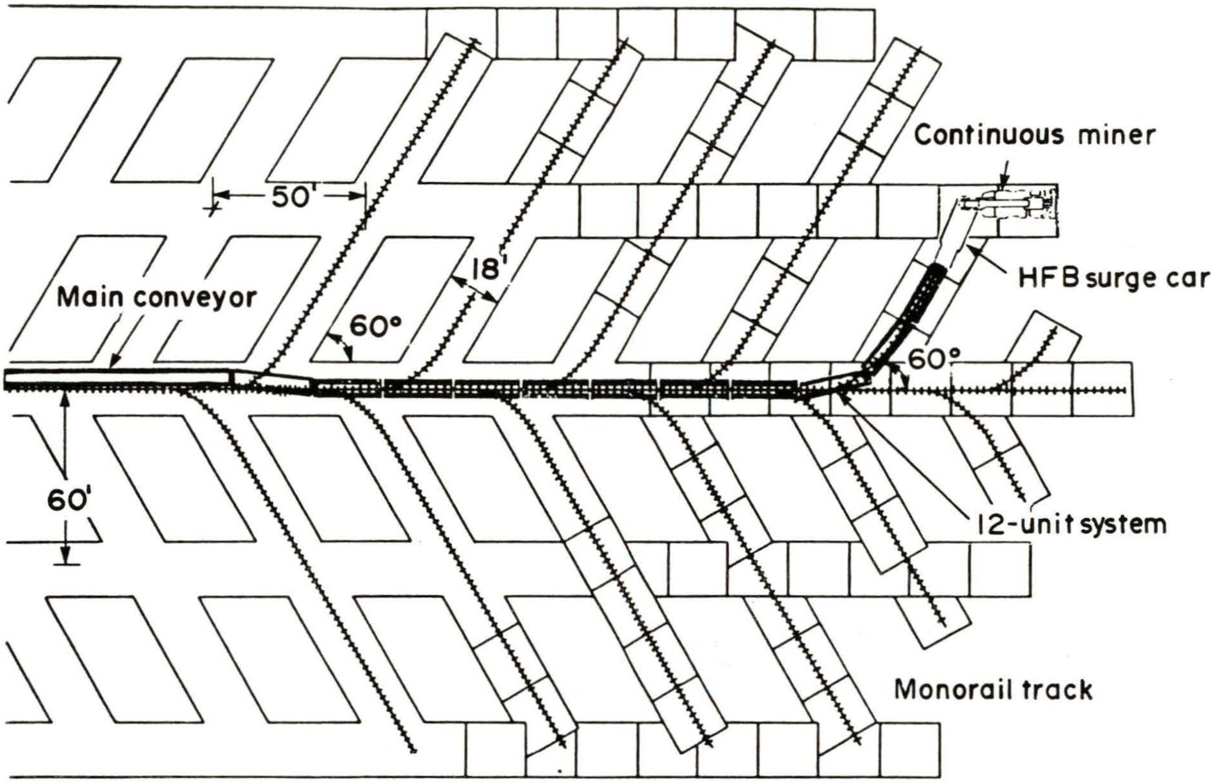


FIGURE 27. — Five-entry mine plan.

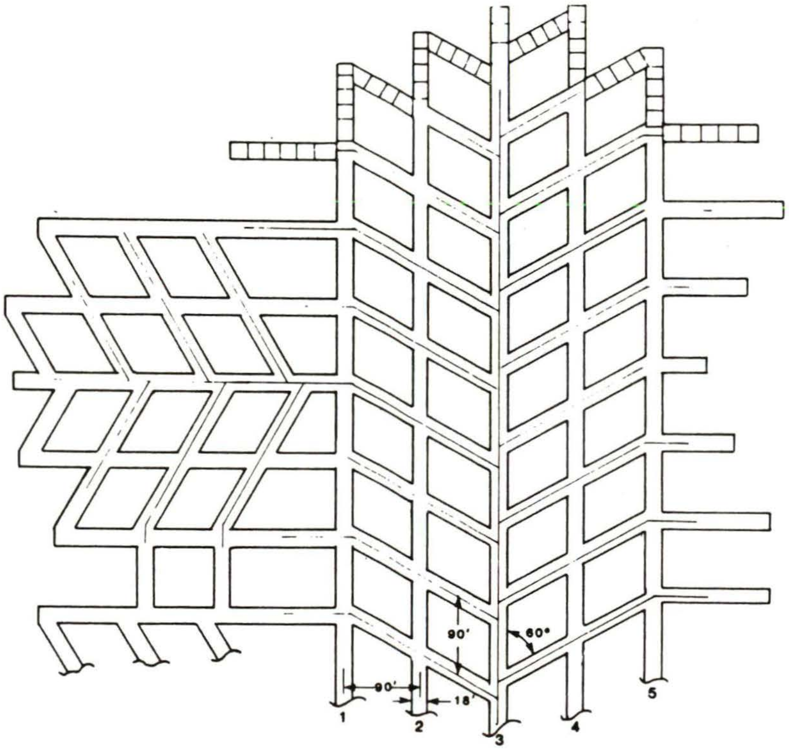


FIGURE 28. — Five-entry 60 degree mine.

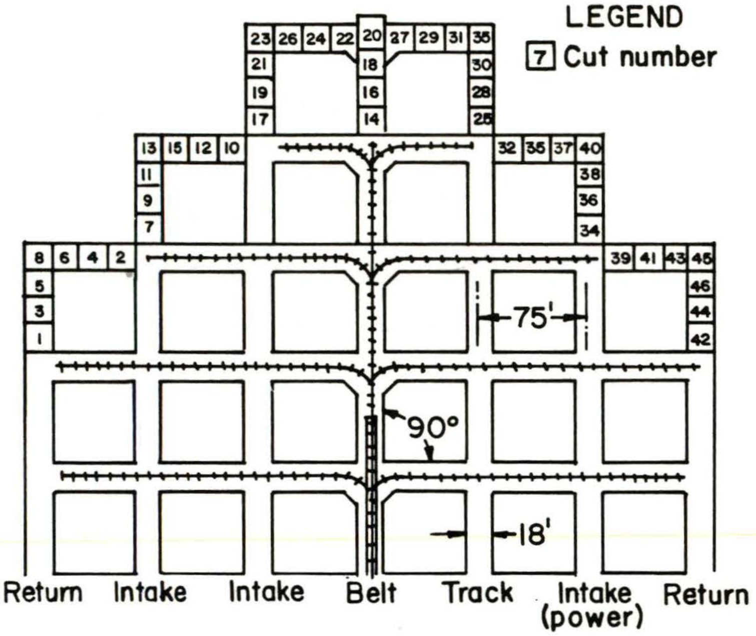


FIGURE 29. — Seven-entry mine plan.

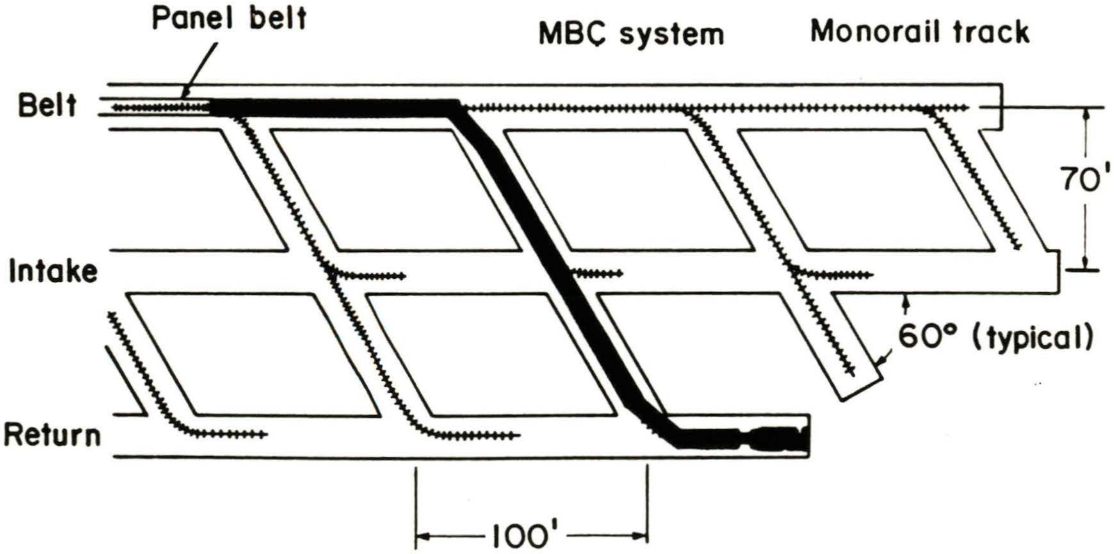


FIGURE 30. — Mine plan for longwall panel-entry development.

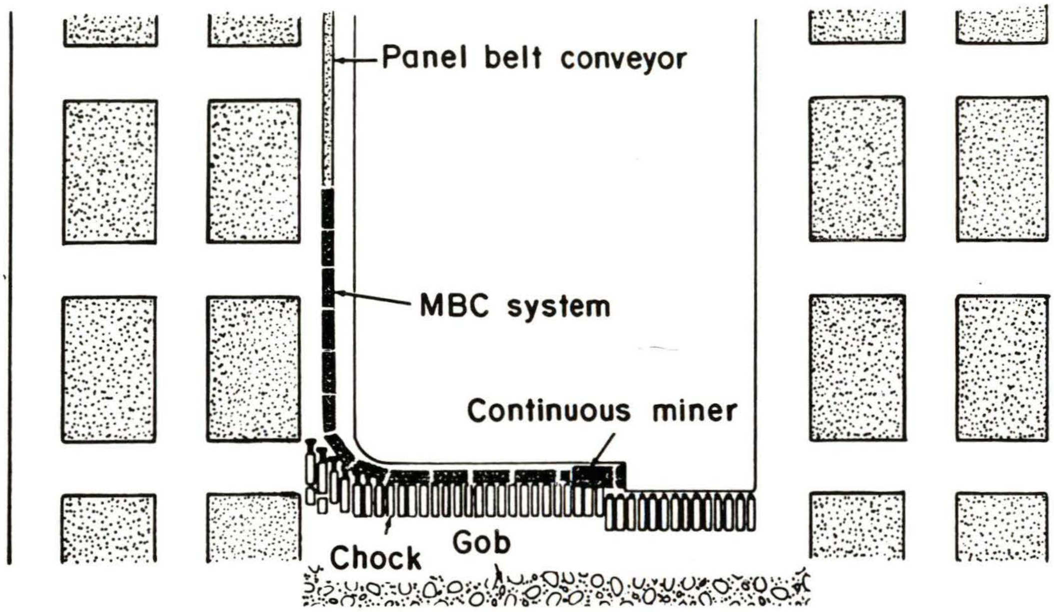


FIGURE 31. — MBC used with shortwall mining system.

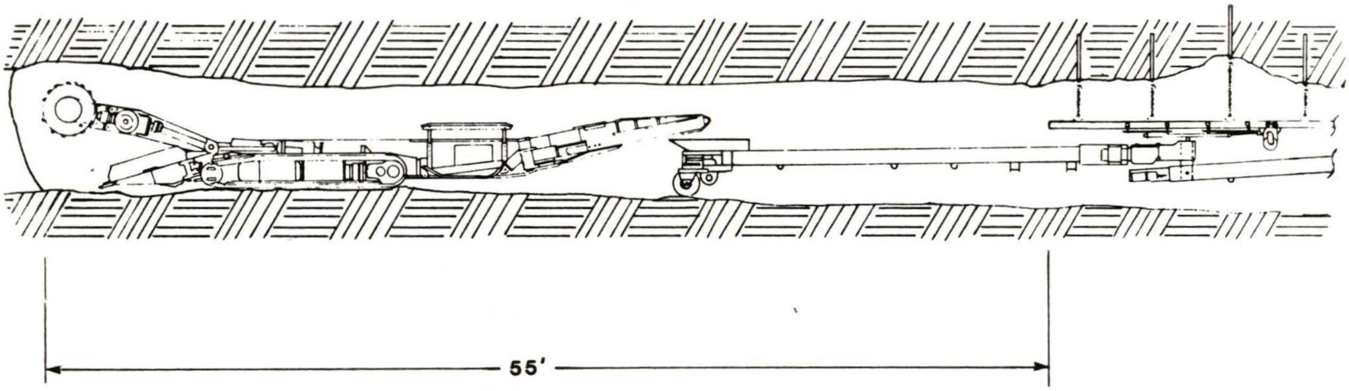


FIGURE 32. — MBC with continuous miner.

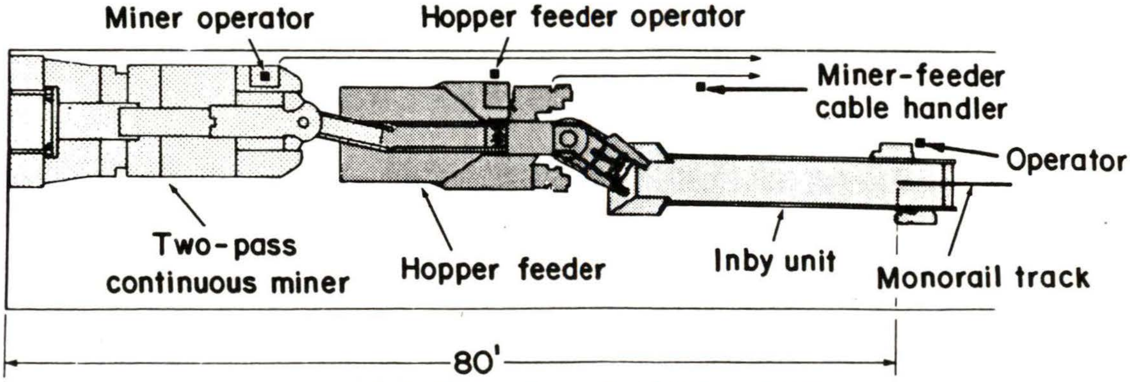


FIGURE 33. — MBC used with Hopper-Feeder.

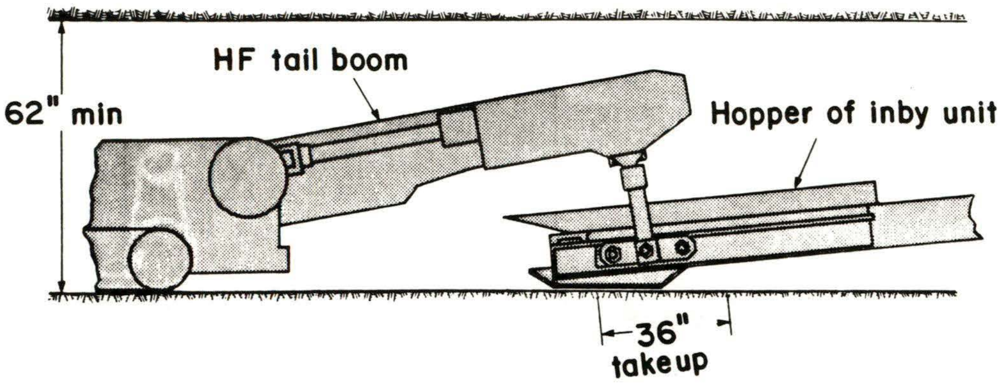


FIGURE 34. — MBC-Hopper Feeder interface.

installation in high and uneven roof conditions. Figure 8 shows the two types of installation hardware. The size and length of the roof bolt would depend upon local mine conditions. Roof bolts that are part of the roof-control plan cannot be used for monorail suspension. Suspension on 4-ft centers is recommended for straight track sections. Suspension on 3-ft centers is recommended for curved track sections.

Monorail track can be installed either on or off cycle with the cutting plan, depending on the mine and cut plan selected. Oncycle installation plans would require the roof-bolter crew to install monorail track in a cut immediately after the cut is bolted. Off-cycle installation plans would allow monorail-track installation during an idle shift. Monorail-track layout must be consistent with as-cut mine geometry to ensure adequate clearance at turnouts. Figure 35 shows a typical track layout for 18-ft-wide entries and 60 degree crosscuts. The track should always be installed to maintain clearance for personnel at all points on the right side of the MBC.

CONCLUSION

The MBC system as developed and tested is a prototype, continuous face haulage system. The surface tests and most importantly, the underground demonstration, have demonstrated conclusively that this innovative haulage system offers the mining industry potential benefits for increased production, while providing for greater personnel safety. The MBC can be a viable and cost effective means fo continuous haulage.

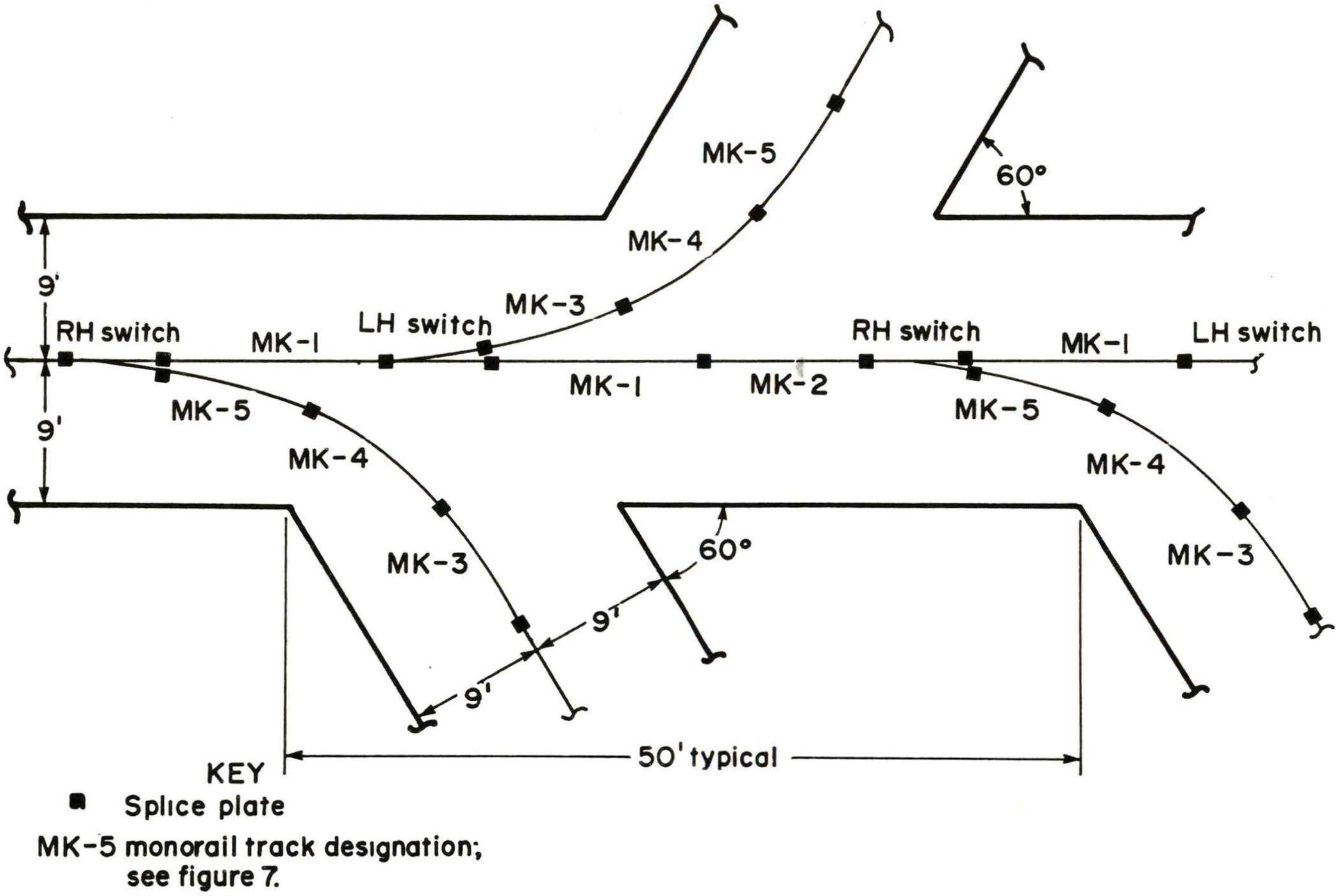


FIGURE 35. — Monorail track installation plan.