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Continuous Surface Mine Materials Handling Systems

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Summary

This paper presents a review of three ongoing research projects dealing with continuous materials handling systems in open-pit mines in the USA. The systems include mine-run-rock conveyors, high-angle conveyors, and movable in-pit crushers. These material handling systems are being evaluated and applied to mining systems primarily to reduce the dependency on diesel fuel and to reduce mining costs.

1. Introduction

Open-pit mining operations in the United States handle about $2.3 \cdot 10^9$ metric tons* of ore and waste each year excluding coal, sand, and gravel. Most of this material is handled by trucks. In recent years, truck haulage costs have increased to where they account for more than half of all pit operation costs. It is expected that this figure will continue to rise, primarily because of increasing fuel and labor costs.

During the past 20 years, several large mining operations have been very successful in developing high capacity conveyor systems. Some examples are: the brown coal industry in Germany, iron mining in the USSR, copper mining in Zambia, and tar sand operations in northwest Canada. One of the largest mines in the world is at Fortuna, Germany, where over 14,000 t/h are handled by conveyor belts. In the USA, several high-capacity conveying systems have been developed for applications other than mining. Examples are the Oroville Dam project and a system which handles 18,100 t/h loading iron ore barges on the Great Lakes. The outstanding feature regarding these installations is their high continuous capacity, which results in substantially lower costs.

Most of the systems mentioned handle alluvial-type material consisting mainly of fines, and have the following equipment in common: (1) wheel excavators or reclaimers, (2) shiftable conveyors, (3) crawler-mounted stackers, and (4) steel cables core belting. According to Dennehy [1], a comparative recent assessment made in the U.S. and Europe revealed that there are some 80 different types of conveyors, 10 types of elevators, and 50 types of feeders. Conveyor technology in the lignite deposits of West Germany is perhaps the most developed and is now spreading to the tar sand and coal projects of western North America.

Many surface mines in the United States today move comparably large volumes of material; however, they must handle rock, not fines or alluvial material. As compared to alluvial material, rock normally must be put through a primary crushing unit and reduced in size prior to conveying. Rock handling systems also have higher capital and operating costs per ton than those handling fine material, because a more rugged installation is required and more belt wear and damage will occur.

For some years now, the merits of employing belt conveyors in the U.S. mines for primary open-pit haulage have been discussed and argued. Few hard rock operators have been influenced by the advantages of belt conveyors, preferring instead the more flexible and initially less costly truck haulage. There are two significant rock moving operations in North America now using conveyors for haulage in open-pit mines. The first is at Twin Buttes in Arizona, where conveyors have been used since 1965. In 1979, this mine moved 45,268,494 tons of ore and waste. The second operation is at the Sierrita open-pit copper mine, also in Arizona, which moved 58,065,598 tons of ore and waste in 1979. Because of this limited use of conveyor haulage systems in U.S. surface mines, it is difficult to analyze and compare their productivity with present truck haulage.

Both Twin Buttes and Sierrita require trucking of ore to the in-pit crushers. Recent developments in large front-end loaders, where bucket sizes have now surpassed the 19 m^3 mark, suggest that a loader-conveyor combination with load haul dump units feeding directly to movable conveyors could be more efficient. However, it appears that further development of alternative rock handling systems to reduce trucks depends on either (1) the availability of large movable crushing systems feeding conventional or high angle conveyors or (2) the development of conveying systems to handle run-of-mine material with no crushing necessary.

Both approaches have advantages; the first alternative is the more technically feasible from the standpoint of the crusher, since manufacturers presently have such machines on the market and the capability of developing improved models.

* all tons (t) in this paper are metric tons

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However, a high angle conveyor will require more research and development. From an economic assessment, the second alternative, by eliminating the crusher and trucks from the pit, could be the lowest cost system. Technically, again, the development of conveying systems to handle plus 50 cm material is still in the research stage.

Based on this analysis, the U.S. Bureau of Mines is conducting three research projects involving alternative haulage systems. They are:

1. A mine-run-rock conveyor system capable of handling rocks up to 150 cm in size.
2. A high angle conveyor capable of moving material at angles up to 45 degress.
3. A large movable crusher with feed through capacities of 1,800 to 3,600 t/h.

2. Mine-Run-Rock Conveyor

The main factor that restricts lump size for conventional belt conveyors is collision impact between the rock on the moving belt and the fixed idlers, as such impact damages the conveyor belt idlers. Major improvements have recently been made in this area. In addition to steeper troughing angles, the flexible roller base, known as the Garland* system, has been developed. Its design principle is the interlocking of several rollers with chain links, offering a limited amount of roller flexibility. The Garland can be deformed to change its trough angle, dependent on the material passing over it. This results in elimination of part of the kinetic energy of the impact load. However, even using a Garland conveying system, it would be necessary in most U.S. metal and nonmetal surface mines to provide primary crushing ahead of the belt system.

This section of the paper describes the results of work completed to date by R.A. Hanson Company, Inc., under contract to the U.S. Bureau of Mines. This research and development effort covers the design, fabrication, and testing of two prototype mine-run-rock (MRR) or large rock conveyors.

3. Current Applicable Conveyor Technology

A review of the literature, visits to mining and manufacturing operations, and discussions with researchers led to the investigation of five conveyor concepts as possible candidates for handling run-of-mine material in U.S. mines. The five systems are:

1. Idler Supported Endless Belt (ISEB).
2. Car and Rail Supported Endless Belt (CRSEB).
3. Cable and Pulley Supported Endless Belt (CPSEB).
4. Car Train.
5. Belt Train.

3.1 Idler Supported Endless Belt (ISEB)

Idler supported endless belts carrying large rocks are basically conventional conveyors with stronger components and closer idler spacing. They are characterized by flat belts with side structures to keep material on the belt. Many crushers are fed with a short belt of this type from the loading pockets. Two firms, Bando Chemical Industries and Réalisation d'Equipments Industriels (REI), have developed and manufactured ISEB conveyors capable of handling material to 1.5 m in size. The Bando equipment has been used in a municipal land reclamation project near Osaka, Japan; and REI of Paris, France, has designed and manufactured rock-belt loaders for over 10 years with installations in Spain, Greece, France, Cuba, Great Britain, and Italy.

3.2 Car and Rail Support Endless Belt (CRSEB)

The CRSEB consists of a belt supported by moving cars. Each car is a troughed crossmember with wheels that roll on upper carrying and lower return rails. These cars are connected by roller chains, and pulled by the force of friction between the loaded conveyor belt and the car. Patents on this concept have been filed in the Soviet Union.

The first prototype was installed in 1970 at the Karatau mining operation in Hazakhstan, USSR, to transfer blasted phosphate ore from the open pit to the crushing plant. As shown in Fig. 1, material up to 1.5 m in size was handled at rates of

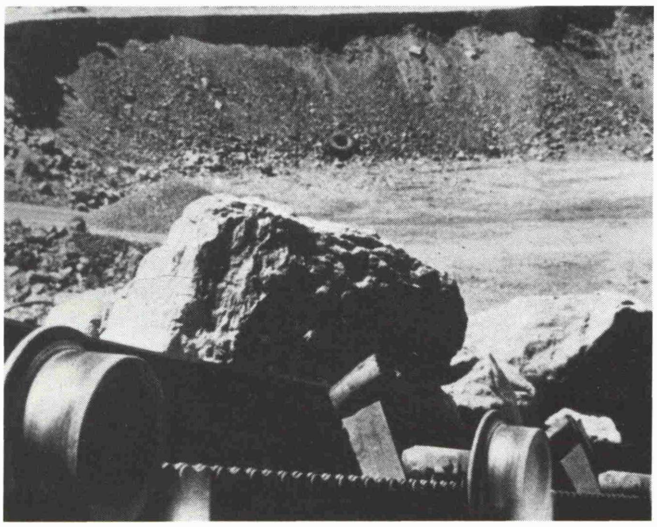


Fig. 1: Large rock on USSR CRSEB conveyor (Photo courtesy of Licensintorg, USSR)

1,500 t/h up an inclination of 20 degrees. This 52 m long prototype conveyor used a 1.2 m wide belt of fabric core construction driven by a single drive pulley. At the loading area, several rows of truck tires supported the belt and provided shock absorption.

An operational rock conveyor that is 1,250 m long in three flights is now being built at the Karatau mine (Fig. 2). This conveyor carries a 1.6 m belt and incorporates several improved design changes. The cars are curved rather than troughed and use smaller diameter wheels.

Joy Manufacturing has experimented with a car and rail conveyor system with a flexible belt that is hard-bolted to small cars that run on rails. This equipment is designed to convey 15 cm minus material around horizontal curves.

3.3 Cable and Pulley Supported Endless Belt (CPSEB)

This method uses wire rope as the power transmitting medium. The belt is made of rubber vulcanized around a fabric envelope and stiffened laterally with transverse

* Reference to specific equipment, trade names, or manufacturers does not imply endorsement by the Bureau of Mines.

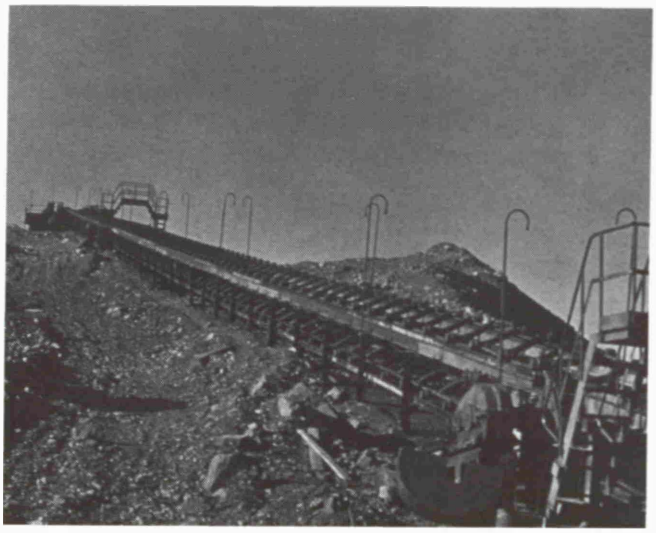


Fig. 2: First flight of 1,250 m CRSEB conveyor at Karatau mine (Photo courtesy of Licensintorg, USSR)

flexible steel rods and is carried on the wire ropes supported by pulleys. These pulleys are mounted on line stands located at intervals along the conveyor route.

Cable Belt Ltd. of England is the designer and sole manufacturer of this conveyor method. A paper by Ian M. Thomson [2] outlines the design evolution of the method and discusses in detail the major components of the system. This conveyor was designed to transport run-of-mine coal or crushed rock at high speeds over long distances. It is used extensively in Great Britain, with several installations in the United States. One of these is a 9,910 m length conveyor at the Anamax Company's copper mining operations near Sahuarita, Arizona.

3.4 Car Train

The quasi-continuous car train system is comprised of a series of mine cars traveling on railroad-type trucks. Electrically-driven, rubber-tired drive wheels act against continuous steel flanges on the sides of the cars, moving the train forward. Several trains travel on a single loop of track and are propelled by multiple-driven stations positioned along the tracks.

The car train was developed in France for use in a nickel mine of the Societé le Nickel (SLN) of Paris. The method is referred to as SECCAM. Two SECCAM systems, 19.3 and 2.4 km long, were built on the island of New Caledonia to transport nickel ore from a mine in the mountains to a port facility. Ultimately, both installations were abandoned in favor of conventional conveyor systems.

3.5 Belt Train

Two systems have been developed that use a belt riding on, or suspended from, a rail-mounted car; one in West Germany, and one in the USSR.

The ASBZ system developed in West Germany is an experimental quasi-continuous, high-speed facility for transporting bulk raw materials over long distances. The trains are driven by linear motors on an elevated, column-supported, two-rail track. The prototype system handled 19,000 m³/h of crushed rock at speeds of 1,200 to 1,300 m/min over a 4,900 m track. This installation has now been dismantled. Applications for the ASBZ system are limited to high volumes and long distances due to the extensive and costly loading and unloading installations required.

The Soviets have built a belt train which is another quasi-continuous system composed of a series of connected cars which travel on rails. On horizontal or low-incline tracks, the motive power is furnished by rubber tires rotating in a horizontal plane reacting against the structure of the cars. On high-incline tracks, a linear induction motor is used. This Soviet system, consisting of ten 122 m long trains, was used at the Sarbai Quarry. It handled material up to 1.0 m in size at 1,500 m³/h over a distance of 6.4 km. The system is still under development.

4. Crib and Cable Supported Endless Belt

Following their investigation, the R.A. Hanson Company designed another conveyor system to handle large rock. The crib and cable supported endless belt (CCSEB) is shown in Fig. 3 and integrates design features of both the CRSEB and CPSEB methods. It uses a steel core belt supported on steel, troughed cribs attached by mechanical clamps to a wire rope located on each side of the crib. The wire rope is supported by pulleys mounted on line stands along the length of the conveyor. The belt is driven by a conventional drive system and the cribs are pulled along by friction of the loaded belt.

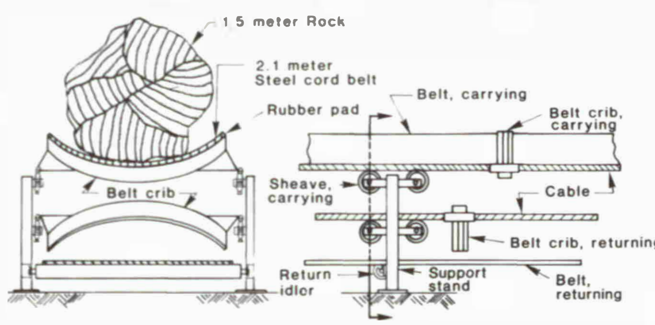


Fig. 3: Crib and cable supported endless belt

Preliminary design for three of these systems, the ISEB, CRSEB, and CCSEB, was completed to the extent that budgetary acquisition costs and operating costs for production models could be established. Acquisition costs for a 360 m section are shown in Fig. 4.

	ISEB	CRSEB	CCSEB
Labor ($1000)	$ 553	$ 553	$ 518
Materials ($1000)	1,921	1,619	1,483
SGA and Profit ($1000)	1,423	1,249	1,151
Total Cost ($1000)	$3,897	$3,421	$3,152
Cost per Foot	$3,330	$2,924	$2,694

Fig. 4: Estimated production model costs of MRR conveyors

The operating costs of the three different systems were also calculated as part of the investigation. Based on both the acquisition and operating costs, it was concluded that the CRSEB and CCSEB systems could transport run-of-mine material for the least cost per ton kilometer — $ 0.102 and $ 0.115, respectively. The estimate for the ISEB system was $ 0.155 per ton kilometer.

5. Prototype Testing Program and Facility

Based on this investigation and analysis, two concepts have been selected for testing, the Crib and Cable Supported Endless Belt and a modified Car and Rail Supported Endless Belt. A test facility, illustrated in Fig. 5, is being fabricated. The facility will be approximately 46 m in length, 12 m wide, and stand 14 m high. Large rocks, 1.5 m in diameter, will be loaded with a boom crane into the vertical chute at one end of the facility. From the bottom of these chutes at the end of the facility, the material will be carried by 2.2 m wide belts up to a 20° incline and dropped into the chute at the other end, thereby recycling the rock in a continuous conveyor-chute-conveyor-chute system. Both conveyor belts will be powered by an electric motor through a chain and sprocket drive.

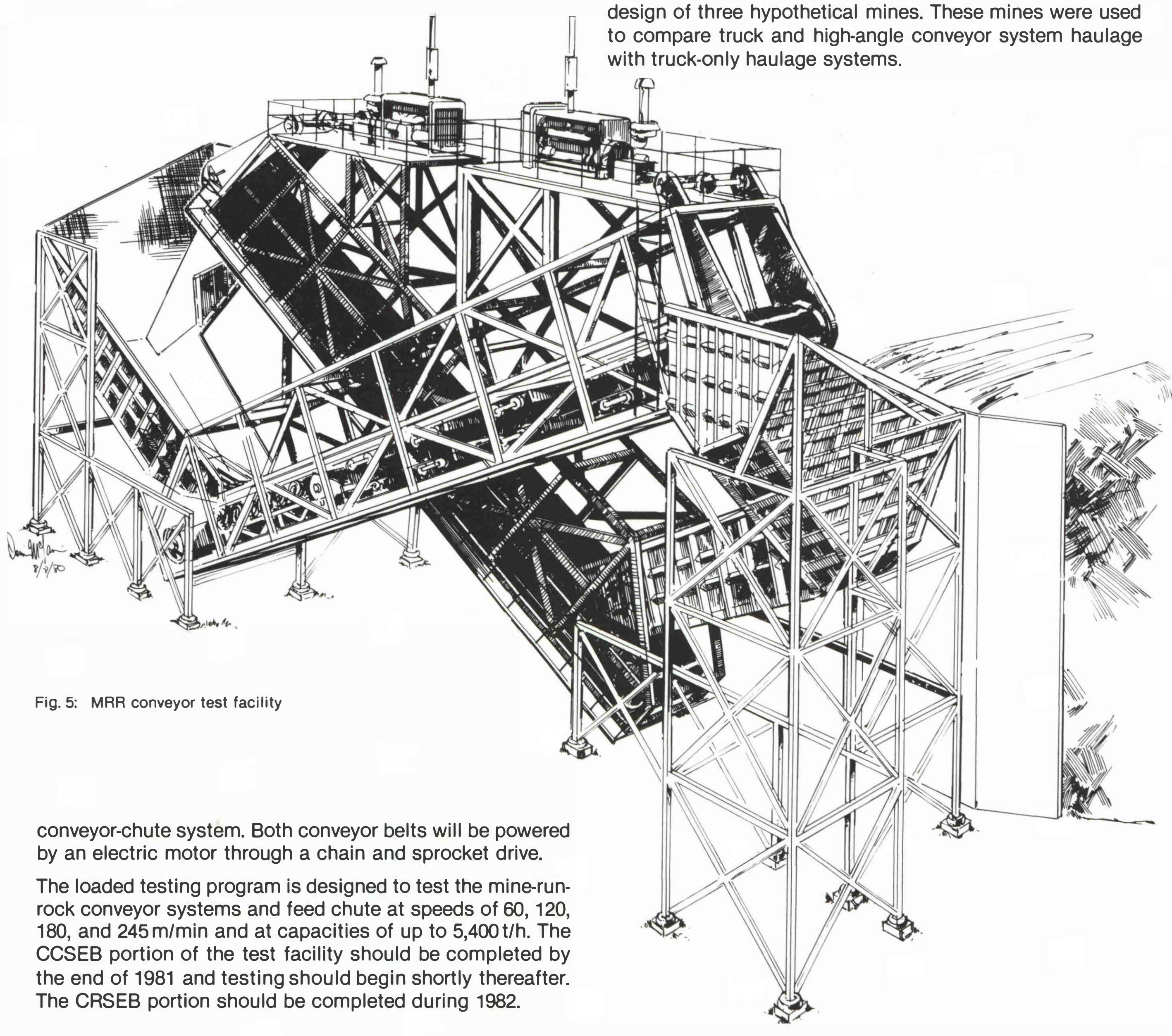


Fig. 5: MRR conveyor test facility

The loaded testing program is designed to test the mine-run-rock conveyor systems and feed chute at speeds of 60, 120, 180, and 245 m/min and at capacities of up to 5,400 t/h. The CCSEB portion of the test facility should be completed by the end of 1981 and testing should begin shortly thereafter. The CRSEB portion should be completed during 1982.

6. High-Angle Conveyors

One of the difficulties of conveyor haulage is the inherent slope restriction of approximately 18° for handling material. Unfortunately, this does not coincide with the typical slope of open-pit walls, which generally range between 38 and 45 degrees. Conventional conveyors must, therefore, either be placed in a notch to reduce this angle or run out of the pit in a switchback configuration. Both methods pose serious problems to the day-to-day operation of the mine. A possible solution is a conveyor with a lift capability of approximately 45° capable of handling high tonnages and high lifts.

Dravo Corporation of Pittsburgh, Pennsylvania, under contract to the U.S. Bureau of Mines, conducted a study of the technical and economic feasibility of using a high-angle conveyor system in open-pit mines in the U.S. as an alternative to truck haulage. First, a survey of the metal and nonmetal surface mining industry in the U.S. was conducted to determine the performance requirements for high-angle conveyors. The mines included copper, taconite, phosphate, molybdenum, and gold. The data collected and the input from mine planners and operators formed the basis for the requirements of a high-angle conveyor system and the design of three hypothetical mines. These mines were used to compare truck and high-angle conveyor system haulage with truck-only haulage systems.

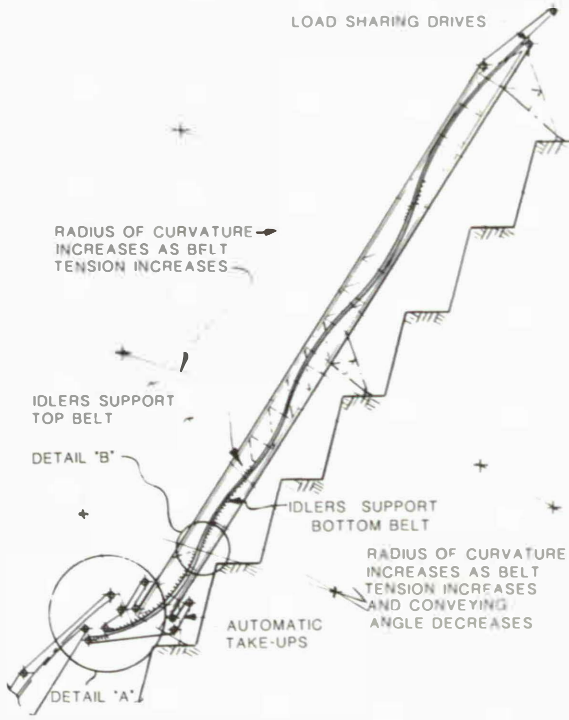


Fig. 6: Snake sandwich conveyor

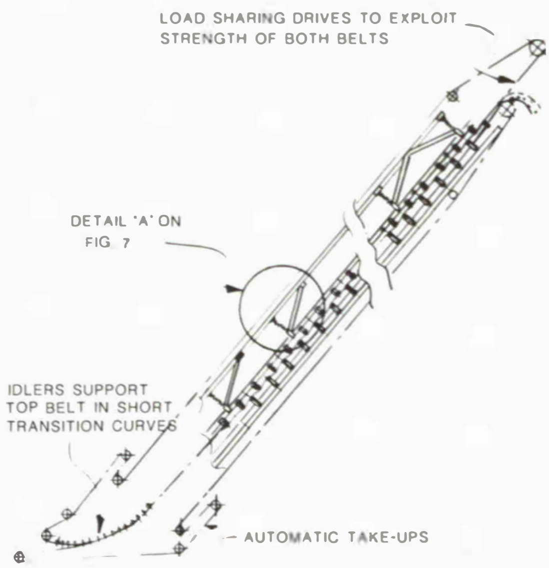


Fig. 7: Mechanically pressured sandwich conveyor

6.1 Minimum Performance Requirements for a High-Angle Conveyor

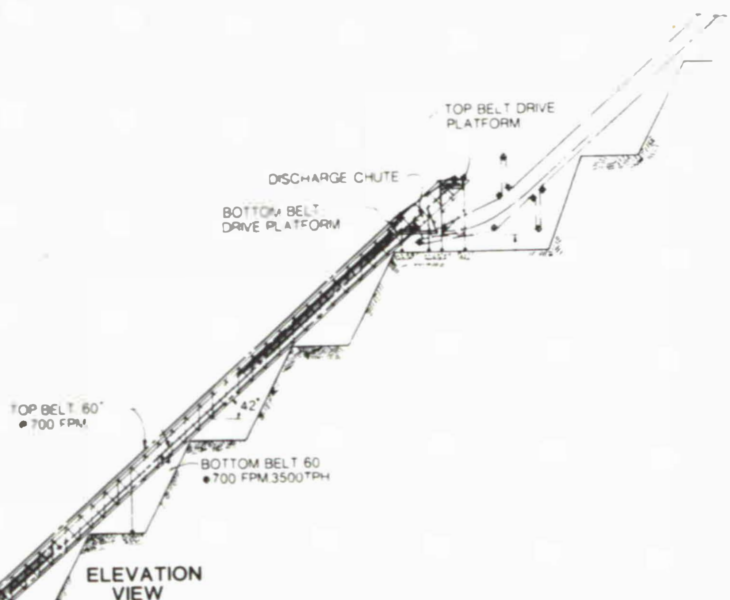
After reviewing all the information collected, the following average performance requirements were developed:

1. **Material Characteristics:** angular, hard, slightly abrasive, 38° of repose.
2. **Lump Size:** 203 mm maximum lump size.
3. **Capacity:** 3,200 t/h
4. **Lift:** maximum possible based on equipment limitations.
5. **Mobility:** move at least once every 2 years.

Next, a state-of-the-art study of high-angle conveyors was conducted and involved such conveyors as bucket ladders, belts with partitions, and sandwich belts. After a thorough analysis of the collected data, an evaluation was performed in order to determine which conveying concept and system for a high-angle conveying unit best satisfies the needs of the mine operators.

Sixteen methods were considered including a linearly accelerated bucket column. These included high-capacity bucket ladders to be carried by chains, cables, or belts; pocket belts; pipe belts; sandwich belts; slurry conveyors; and screw conveyors. An evaluation of these methods showed that the sandwich belts would best meet the performance requirements for the surface mines surveyed. Three sandwich belts were then investigated:

1. The snake sandwich belt (Fig. 6).
2. The mechanically-pressured sandwich belt (Fig. 7).
3. The pneumatically-pressured sandwich belt (Fig. 8).



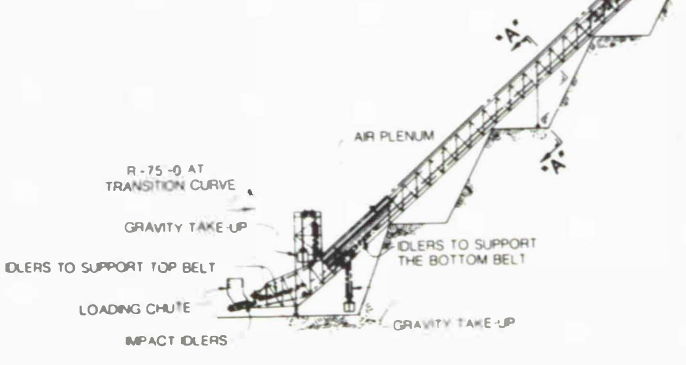


Fig. 8: Pneumatically pressured sandwich conveyor

Of these, the pneumatically-pressured belt was selected as the preferred method; while the mechanical and snake belts ranked a close second and third, respectively. A pneumatically-pressed sandwich conveyor module of 96 m of lift to convey at 3,200 t/h was then developed in more detail. Erected price, operating, maintenance, and mobility costs were determined. Although the conveyor design was based on 3,200 t/h, the pneumatically-pressed sandwich belt is capable of conveying tonnages in excess of 5,000 t/h.

7. Movable In-Pit Crusher

The introduction of mobile crushers occurred in 1954 when Krupp first built a movable primary crusher on crawlers. Since then, others have been built and mounted on walkers, tires, skids, and rails. Their principal use today is in limestone pits, where lower tonnage rates are generally required (under 1,000 t/h), and where the operation is generally not around the clock, thus providing time for maintaining the crusher system.

The use of movable crushers in large open-pit mines is presently being studied by Gard, Inc. under contract to the U.S. Bureau of Mines. The objective is to determine the need, applicability, and economic limitations of movable in-pit crushing/conveying systems. The areas of investigation involve a survey of a number of large open-pit mines to determine their needs and requirements for in-pit crushing, an examination of the state-of-the-art of movable crusher technology, and an integration of the results of these two into a unified concept for in-pit crushing/conveying.

Mine operators surveyed were all interested in movable crushers and had an almost universal preference for gyratory-type primary crushers, citing their inherent reliability and durability and their relative freedom from clogging. All operators preferred large crushers with capabilities of 2,700 to 3,600 t/h to minimize the number of conveyors needed. One operator indicated the possible need to move a crusher every 9 months to 1 year; most agreed a move every 2 years would be sufficient, and some would tolerate a system at one location for 5 years.

It was determined that large primary crushers can be moved from the main grinding circuits out into the pit by setting the crusher on a large frame and using tracks, wheels, or walking mechanisms. This portability promotes minimum haulage distances between the shovels and the crusher by allowing the crusher to be placed at a location central to the shovels. The expense of the large supporting structures and moving mechanisms is justified by their contribution to reduced fuel consumption and fewer haulage vehicles and, consequently fewer operators and maintenance personnel. In addition, the ease of crusher movement contributes to increased production levels.

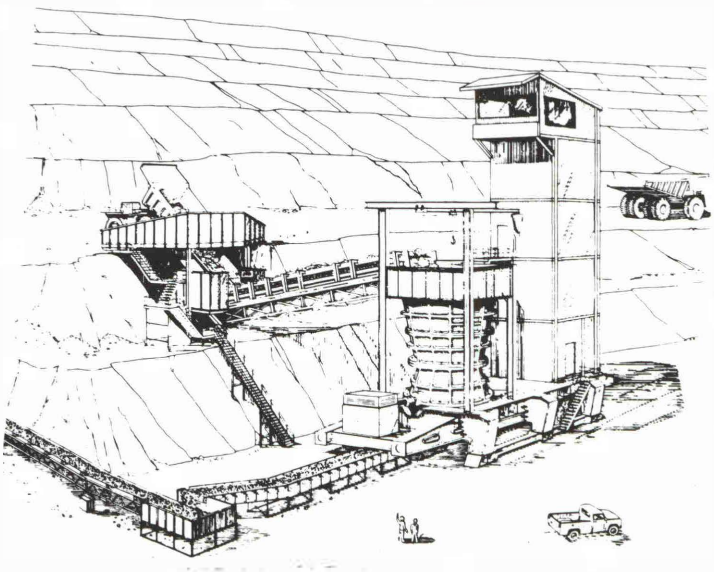


Fig. 9: Movable crusher

Although a fully-movable large gyratory crusher is a large piece of equipment to move, the technology for moving such large structures is available. Walkers are used in the mining industry already on large draglines and are compatible with this type of equipment movement. When the need to move the crusher arises, commerically available transporters can be attached to the heavy structural frame and removed when the move has been completed. The transporter should serve the moving needs of all crushers in the mine complex and be available between moves for other plant requirements.

A movable crusher could also be recessed in a pit bench and a feed hopper installed above the crusher to facilitate the unloading of the trucks, or the crusher station could be positioned parallel to the toe of the bench with rock being fed by a rock belt or apron feeder from the next higher bench. Fig. 9 represents an artist's concept of the crusher at the toe of the bench.

Removal of the crushed product can be by conventional idler, steel cable belt conveyors set in the mine at the normal 18°, or high-angle sandwich-belt conveyors. Fig. 10 shows another artist's concept of a movable crusher with a high-angle conveyor.

8. Comparison of Haulage Systems

The pneumatically-pressed sandwich belt was compared to truck haulage using three hypothetical mines representing the copper, taconite, and phosphate industries. Included in the comparative analysis was a movable in-pit crusher. Based on the need expressed by mine personnel for optimum flexibility within the pit, it was determined that in all three cases trucks would be used to haul the blasted material from the mine face to the in-pit crushers. The crushers then fed the high-angle conveyors, which elevated the ore and waste material to the top of the pit. However, the out-of-pit haulage systems differ for the three different hypothetical mines.

The possibility of truck haulage outside the pit was considered in all three high-angle conveyor applications. Such a system proved to be economically favorable in the hypothetical taconite mine when compared to the conventional haulage system and examined within the specified return on investment (ROI) of 10 to 15 percent. The high-angle conveyor system for the phosphate mine proved to be economical in only part of this range. Because of the small amount of material that is actually hauled on the surface from the high-angle conveyor in this mine plan, the large capital expense required for the installation of a stacker/spreader system could not be justified. It was apparent that surface haulage by trucks was not logical in the copper mine where the out-of-pit truck haulage system would constitute a large portion of the total haulage cost. The high-angle conveying system in the copper mine was complemented by a level, conventional conveying system to the plant and waste dumps, and shiftable conveyors with spreader/stackers at the dump sites. Such a system proved economically favorable. It was also found that a level, conventional conveying system could be used in the taconite mine to further lower the already favorable costs of the system described.

For conventional truck systems, haulage profiles were analyzed to determine the required number of trucks at different stages of the mine life and thus reflect the cost increases in haulage as a function of increasing depth. The number of trucks was also used as the basis for selection of support and maintenance equipment, the cost analysis of the operation being based on 1980 dollars. Manpower costs represented the average requirements throughout the mine life. Capital costs for all major equipment were obtained on budgetary price quotes from various manufacturers during January 1980. The costs of power to operate the facilities are based on the rates charged in a state where the mine might be located.

The dollars per ton of ore figures that were generated represent the price at which the ore must sell to get the specified return in investment. With a 10 percent return on investment after taxes, the selling prices per ton of ore for the truck systems versus the high angle conveyor/movable crusher systems in the copper, taconite, and phosphate mines are $ 1.53 versus $ 1.47, $ 1.26 versus $ 1.22, and $ 2.99 versus $ 2.88 respectively.

9. Conclusions

The rising costs of truck haulage combined with the threat of diesel fuel shortages suggest that the next major advance for U.S. open-pit mining will be increased use of conveyors for both ore and waste.

As mines grow larger and deeper, the amount of savings due to less truck usage becomes greater. Both mine distances and lifts are expected to increase at a rate that will adversely affect even the largest haul truck. Studies have shown that the cost-per-ton per truck goes up exponentially as the distance uphill increases. This is due to lower production-per-hour per truck because of increased cycle time (lower speeds during hauling at high grades over long distances) and additional operating costs per truck (increased fuel consumption and maintenance costs).

At this point, Bureau investigation and analysis have determined that movable crushers, high-angle conveyors, and mine-run-rock conveyors are economically competitive with truck haulage. Feasible concepts have been developed for both the high-angle and mine-run-rock conveyor and the major task ahead is the technical development and testing of these concepts. Presently, ongoing Bureau research will do this testing and development for two mine-run-rock conveyor concepts. In the case of mobile crushers, the technology remains to be demonstrated in operating mines. In 1980, a semi-mobile jaw-type crushing plant was installed in the Meirama open-pit lignite mine in northwestern Spain. Repositioning of this unit will be necessary every 6 months to 2 years, and the feasibility of its use should be confirmed over the next 5 years. As mentioned previously, a gyratory crusher is presently being erected at the Sishen Iron mine in South Africa. It is scheduled to commence operating at the end of 1981.

There are additional advantages not taken into account in an economic analysis of conveyor systems. A conveyor system is far more efficient in terms of energy usage, less labor intensive than a trucking system, and less sensitive to inflation over the years, as replacement and maintenance parts are considerably less. The disadvantages are lack of flexibility, the need to crush large rocks (for conventional conveyors), and the potential consequences of shutdown.

In summary, the benefits to the mining industry from the development and use of these alternative haulage systems are:

1. Elimination of the dependency on diesel fuel.
2. Reduction of mining cost.
3. Reduction of labor force.
4. Reduction of maintenance.
5. Reduction of noise and air pollution.
6. Reduction of haul road cost.

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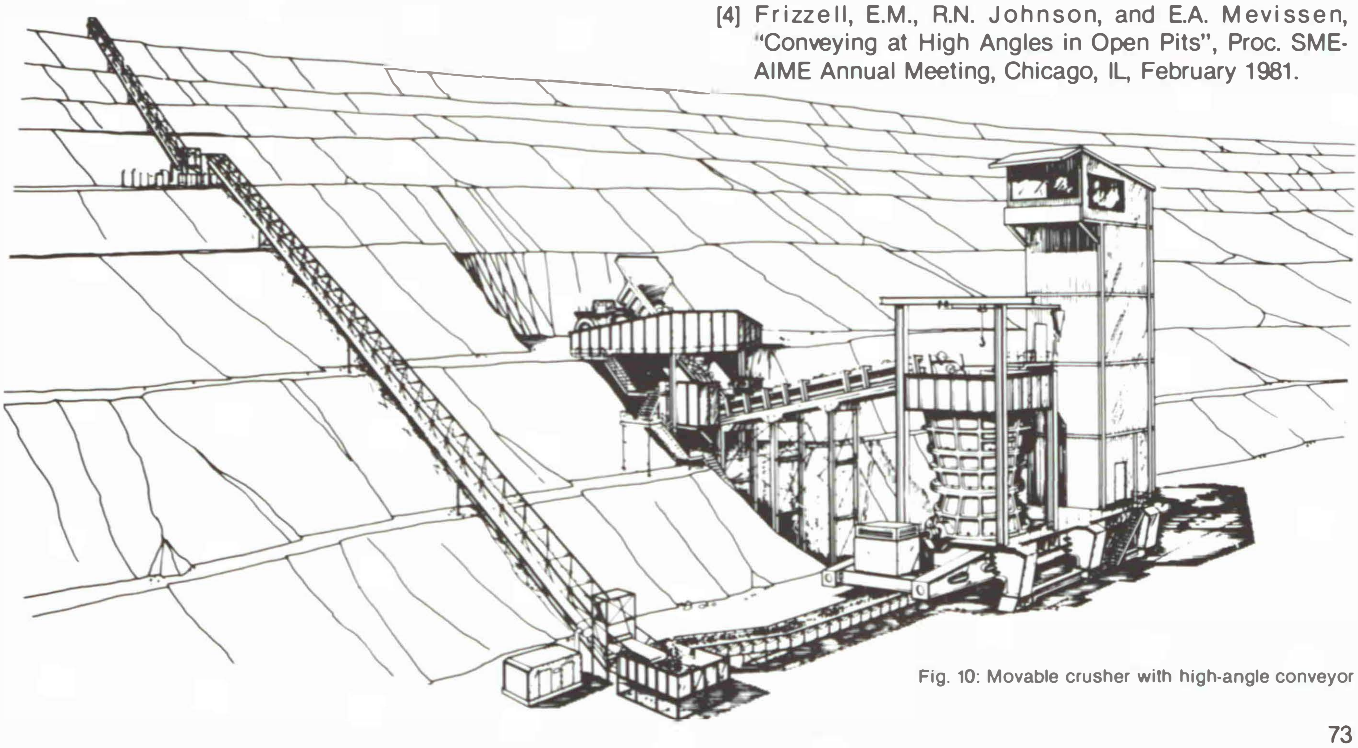

Fig. 10: Movable crusher with high-angle conveyor