

Bucket Wheel Excavator for hard applications and discontinuous transport systems

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1. Summary

For more than two decades Krupp is successfully selling its standard Bucket Wheel Excavators to customers all over the world rely on the high availability and economical low operating costs of the product.

For economical and environmental reasons the Standard BWE has entered the field of hard material mining. Based on this specific knowledge Krupp now offers a new product for mining of hard coal. The significant advantage of the machine compared to conventional mining systems are the low operating costs.

2. Systems for continuous mining of minerals

Krupp Fördertechnik GmbH has been developing and building earthmoving and material handling equipment since the company has been founded over one hundred years ago. The company is known worldwide as one of the leading manufacturers of these machines.

At Lübeck, the former O & K facilities, the first chain bucket excavators were built already in the last century. Up to now Krupp delivered more than 100 excavators of this type.

Since the thirties, when bucket wheel excavators were developed, Krupp has been one of the leading companies engaged in this development.

Today the company offers the entire range of continuous working open pit equipment - excavators and corresponding belt wagons, conveyor belt systems with all components as well as trippers and spreaders.

To complete the above mentioned range of equipment for open pits, Krupp developed and built large semi-mobile or mobile crusher installations.

The latest steps of developments are the Krupp Surface Miner and the Bucket Wheel Excavator for hard coal. The Krupp Surface Miner is performing very well in a hard coal mine of Kazakhstan since the middle of 1995. This machine is designed for applications where materials occur ranging in uniaxial compressive strength from approx. 30 to 80 MPa. See also fig.1 in the appendix.

Based on the long-term operation proven compact type excavator the Krupp Truck Bucket Wheel Excavator, called KTB is actually under design. The working range of the machine allows it to cut semi hard minerals - like hard coal, semi hard shales or mudstones - economically up to 20 MPa with peaks up to 30 MPa. That means Krupp significantly raised the digging ability of bucket wheel excavators.

The main idea behind the machine is to combine the ability to dig hard materials with a BWE which is able to load trucks not strictly connected to a conveyor belt. Therefore the machine gains much more mobility. Further the excavator is able to load trucks while digging the material continuously.

2.1 Standard Bucket Wheel Excavator Systems

Today, the classical excavators for continuous mining operations in open pits with cuttable material are bucket wheel excavators. As far as wear is concerned, the bucket wheel requires less maintenance than a bucket chain. Also, a bucket wheel excavator digs a block in a terrace cut and is therefore well adapted for selective mining of seams imbedded in the block.

Today's theoretical capacities of Bucket Wheel Excavators range from approx. 400 m³/h to 10.000 m³/h. It is not possible to cover this great capacity range by a single type of excavator. Therefore, Krupp differentiates its products into three types:

- 1) Standard Excavators of compact design,
- 2) Medium sized Excavators with compact design or C-frame and discharge belt and
- 3) Giant Excavators with bridge and loading unit.

Standard Excavators are marked by the following features (fig.2):

- The excavator has a two-crawler travel gear which are made of proven standard parts.
- The Excavator has a counterweight boom rigidly connected to the turntable. This provides for good stability.
- The bucket wheel boom is positioned by a hydraulic cylinder.
- Standard mechanical and hydraulically components guaranty high availability and low cost maintenance
- Delivery time is cut to less than twelve months

Krupp Standard Bucket Wheel Excavators have the following main data (fig. 3):

Type		S 100	S 250	S 400	S 630
Theoretical Capacity	m ³ /h	720	1200	2000	3000
Belt width	m	0.8	1.0	1.2	1.4
Bucket wheel outreach	m	6	9	11	15
Length of discharge belt	m	10	16	20	25
Total power installed	kW	75-120	250-350	500-670	1000- 1250
Service mass	t	50-80	120-150	180-220	380-450
Effective Output	bank m ³ /h	150-400	300- 550	550-900	900-1400
	bank m ³ /d	2000-5000	4500-9000	8000-16000	12500-25000

3. Advanced Technics for the diggability of semi hard rocks

3.1 Basic Data

The developments of Bucket Wheel Excavators during the last years were mainly initiated by customers which had special requirements for their application:

1. machines which are able to dig hard material
2. machines which are able to dig thin seams or material layers selectively
3. machines which are able to follow inclined seams or layers
4. machines with a minimum requirement for maintenance
5. machines which are able to operate automatically i.e. without the need of an operator.

The major task during the last years was the development of Standard Bucket Wheel Excavators which are able to dig semi - hard materials such as compacted sandstone, limestone and hard coal.

Figure 7 shows the tendency of the development. Former excavators were mainly designed to dig softer materials like sand, gravel, lignite, clays, chalk, etc.

Today we have strong Bucket Wheel Excavators which have specific digging forces which are about 3 - 6 times as high as those of the early Bucket Wheel Excavators designed for these purposes.

The two machines which stand for the latest step of the development are,

- the S 800, digging **shale and mudstone** at EGAT / Thailand
- and the S400/250, digging **marl/limestone** at TEUTONIA ZEMENT AG in Hannover/Germany.

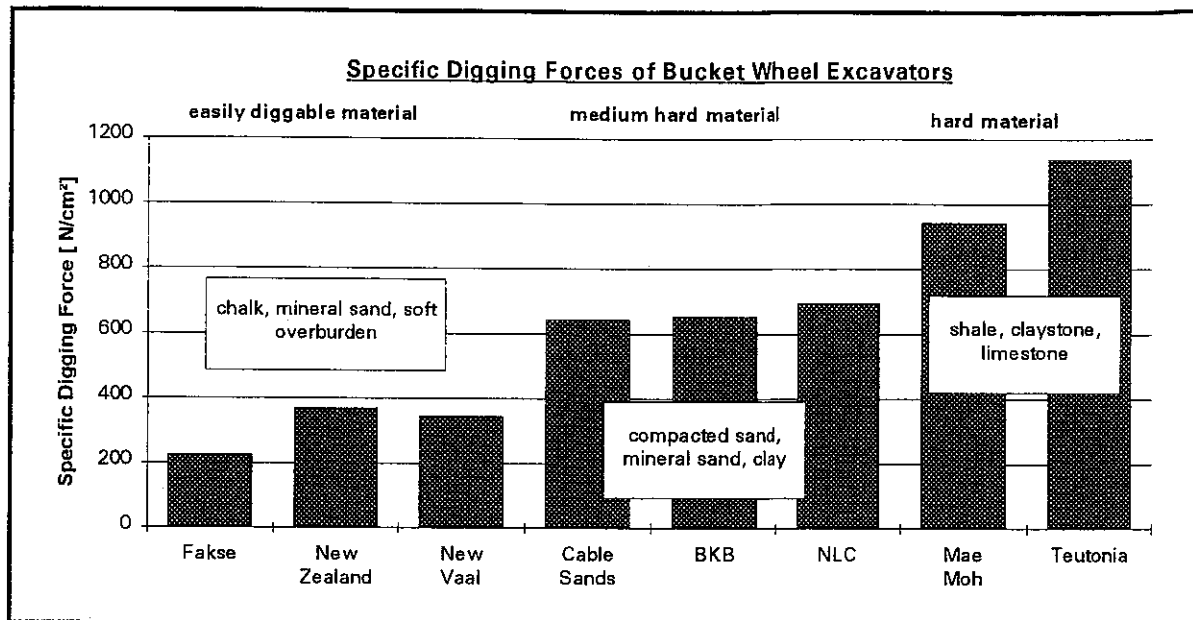


fig. 7

3.2 Digging limestone at Teutonia Zement, Germany

The first project steps of a strong Bucket Wheel Excavator in the limestone quarry of Teutonia Zement AG, Hannover were taken in 1989/1990 when a small compact Bucket Wheel Excavator type S 100 was put into the pit as a test machine. It was not intended to make production with this machine but to find out

- which buckets and teeth would cut this material ?
- what was the required bucket wheel power ?
- which output could be expected in this type of material ?
- which digging technique was successful ?
- how many buckets and precutters would have to be put on the wheel to serve optimum material size ?
- and many more features.

The test was so successful that it was possible to offer a full size machine and a complete system which started operation in 1991.

The BWE S 400/250 in operation at Teutonia now has following main technical features :

- The machine digs 800 t/h limestone continuously.
- The Bucket Wheel drive is more then 300 kW.
- The total installed power is more then 600 kW.
- The service weight of the machine is 185 t.
- And the machine digs the material in conveyable lump sizes. 90 - 95 % of the lumps have edge length of less than 120 mm.

The machine is the first unit of a complete new system. The following picture shows a comparison between the old and the new system in the quarry of Teutonia Zement.

Fig.8 & 9

old system	new system
- drilling - blasting - loading with shovels on a train	direct excavation with Bucket Wheel Excavator
- train transport to primary stationary crusher	conveyor transport to oversize crusher
crushing with large crusher	pre-screening and crushing of oversized material
conveyor transport	conveyor transport

Fig 10: Comparison of old and new system

The new system allows for a direct excavation of the limestone without drilling and blasting. The material consisting of small lumps can be loaded directly onto the conveyor at the face and the cheap conveyor transport can be utilized fully. Only a small extend of the stone need to be crushed to handle oversized lumps. This means the crushing costs are reduced substantially.

Specially for the application at Teutonia Zement the small lump size was an absolute must. The cement plant allows for lumps of less than 120 mm edge length and it was not possible to direct the material flow through the old crusher. Therefore the Bucket Wheel Excavator system had to produce the same size of material as the old system with the big crusher.

3.3 Digging Shale and Mudstone at Mae Moh, Thailand

Another good example for a strong BWE of the new generation and for the conversion of a discontinuously operating system into a continuously operating system with Bucket Wheel Excavator's is the open pit lignite mine Mae Moh in Northern Thailand.

In 1988/89 the idea of replacing the old discontinuously working mining system by an even cheaper system came up, due to the strong competition between the existing contractor companies.

To be able to be more economic, a system had to be installed which gets rid of most of the machines like drilling, blasting, shovels for loading, trucks for transport and finally the big crusher before the material can be loaded onto a conveyor for further transport to the dump, required by the semimobile crusher system.

Such a system is possible nowadays with a strong Bucket Wheel Excavator. After intensive soil tests in 1988 and a lot of planning work this strong Bucket Wheel Excavator started its operation in 1991

Some technical features of the Bucket Wheel Excavator at Sahakol are (fig.11) :

Theoretical capacity : 4100 m³/h

Bucket wheel drive power : 1000 kW

Service weight 835 t

With nearly five years of experience from the first machine we have now some impressive figures at hand, showing that the machine performance and production rate is extremely good and that BWE's are able to dig the hard shales in Mae Moh continuously without blasting. It is a good example that it is possible even under the difficult conditions in Thailand to run a bucket wheel excavator system for more than 6000 hours per year.

No discontinuous operating equipment is required any more and the system really is economic. The economical and technical success of these machine is proven by the fact that you find 5 BWE's operating in the mine today.

3.4 The Wheel and the Digging Technique

Some remarks should be done at this point about the major technical features of the strong new BWE's. It is not only that we build stronger machines than before. The "secret" for the ability of the machines to dig through semi-hard rock lies in its wheel and in its digging technique.

You may note that the wheels of the two machines look different to normal bucket wheels. The bucket wheel is designed as a flange mounted single wall wheel with a very high number of cutting elements (buckets). With the large number of cutting elements it is possible to attain a small cutting area and small lump sizes of the material.

Common bucket wheels are designed with a bucket wheel body on which the individual buckets and precutters are mounted separately. With the new wheel the buckets and teeth are an integral part of the wheel body and the flow of the circumferential forces goes undisturbed from the teeth directly into the main wheel plate.

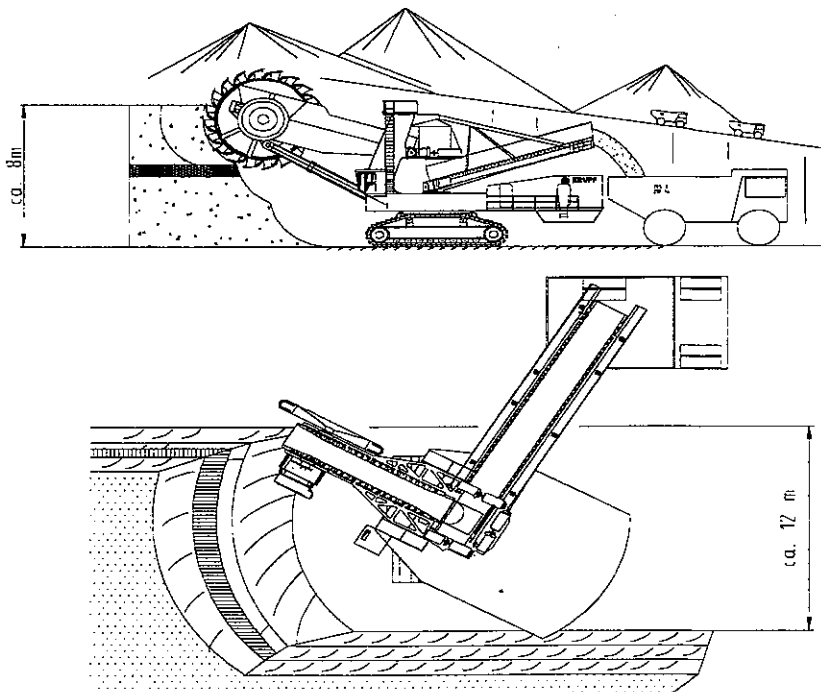
The teeth itself are designed in a long and pointed form. This profile assures that the teeth attack the material with the tip only and the full power of the strong wheel is directed at a small area into the material. The high specific force which is gained by this makes it possible to cut even very hard material. Fig. 12 & 13

Another important point is the digging technique itself.

There are two possible ways of excavating a block, the terrace cut or the drop cut. The terrace cut is highly suitable for soft and easy diggable material because the digging process is easiest to monitor under these conditions and is generally also easiest for the excavator operator to manage. However during the tests with the small BWE in Hannover and also in other applications it has been found that the drop cut operation taking thin shavings is advantageous in hard and brittle material. In the drop cut mode the wheel is in constant contact with the ground, which means that the superstructure cannot shake or swing. In addition to this, any oversize individual lumps broken out of the face are carried along the full height of the face before they are loaded. This means there is more time for each individual lump to be crushed against the face by the bucket wheel than in the terrace cut.

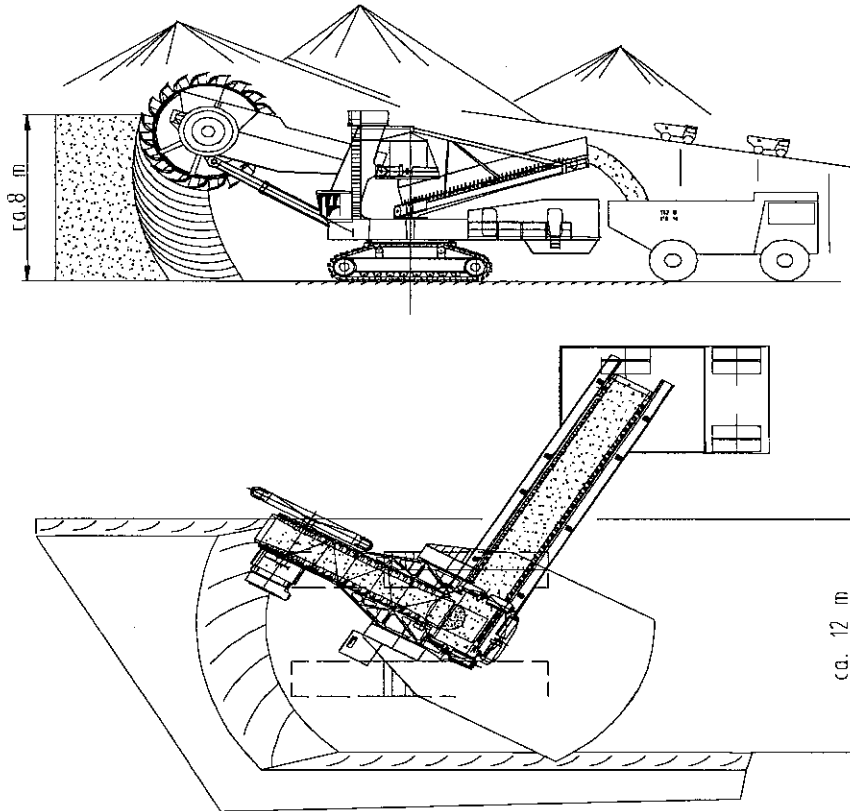
Fig. 14 illustrates the working method of a bucket wheel excavator in **terrace cut**.

This working method allows selective mining of minerals and intermediate waste. The selection is made above the track level.



The material is hauled off by trucks (skip trucks for 100 to 150 st).

In addition to terrace cut, the bucket wheel excavator can also work in **drop cut** as illustrated in fig. 15. In drop cut, the bucket wheel is lowered by the depth of one chip after each change of chip, and if necessary, the machine is traveled back a little. This working method is particularly recommended for harder material to avoid oversized lumps.



4. Technical Concept of the Krupp Truck Bucket Wheel Excavator (KTB)

Frequently the coal to be excavated is not only hard but also deposited in thin seams. There are a number of machines available nowadays which are able to cut selectively thin seams (e.g. surface miners).

The new Standard BWE model is designed to obtain these needs and to provide more mobility and flexibility to mining operations to place the machine in fields of operations up to now reserved for hydraulic excavators. Therefore Krupp designed a Standard- BWE with the ability of more economically loading trucks while continuously digging the mineral.

Further the activities of drill, blast, load and primary crush are combined in one, the continuously digging process of the Bucket Wheel Excavator.

Cleaner mining, i.e. more effective separation between coal and partings or imbedded blind coal is provided and the average grade of the mined coal is higher.

At the end stands a new series of Bucket Wheel Excavators with the ability of most economically loading trucks, due to geological and economical reason of the mines.

4.1 Design of the KTB 2600

The Excavator is a highly compacted machine, with the similar shape as the normal Standard BWE S 250/400. The maximum height of a block is limited to 8 meters. The machine is designed with a theoretical output of 2600 m³/h, and is able to reach an effective output of 2200 m³/h in coal operations.

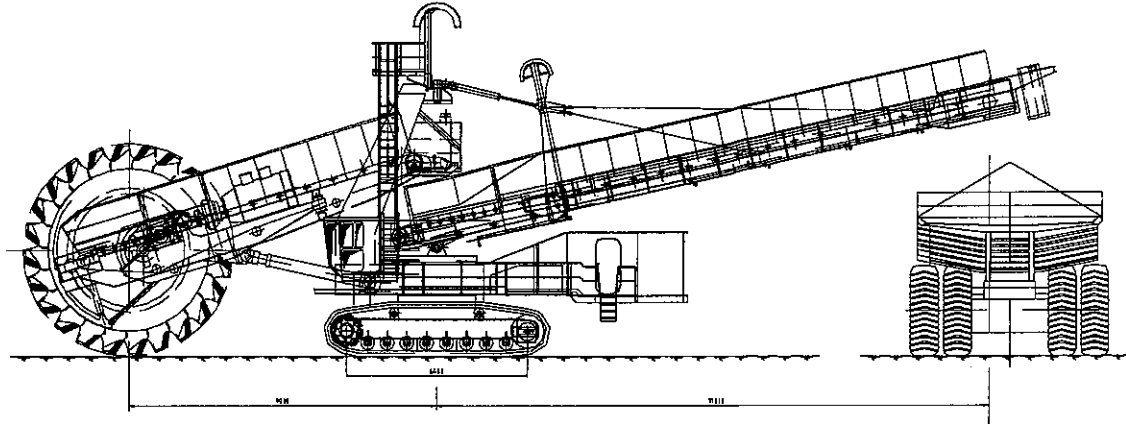


Fig.16: The Standard Bucket Wheel Excavator for Truck Loading

This machine has following main technical features :

- The total installed power is approx. 1700 kW.
- The Bucket Wheel drive is approx. 1000 kW.
- The service weight of the machine is approx. 300 t.
- The Number of buckets is 24.
- The BWE is able to load trucks while offering a rotation time for the trucks of 30 sec. by storing the coal on the belts.
- By using a horizontalised superstructure the permissible inclination while working is increased to 1 : 10, when changing sites to 1 : 6.
- And the machine cuts the material to conveyable lump sizes.

One important thing for the customers is that the whole machine is build by the use of standard mechanical equipment and machine parts to ensure a Krupp service based economical and quick supply with spare- and wearparts.

4.2 Loading of Trucks by storing the material on the belt conveyors

The mining process at the wheel proceeds in 100 % real time onto the individual trucks. This means the continuous mining process is optimally tuned to the loading of the individual trucks, depending on the size of trucks available.

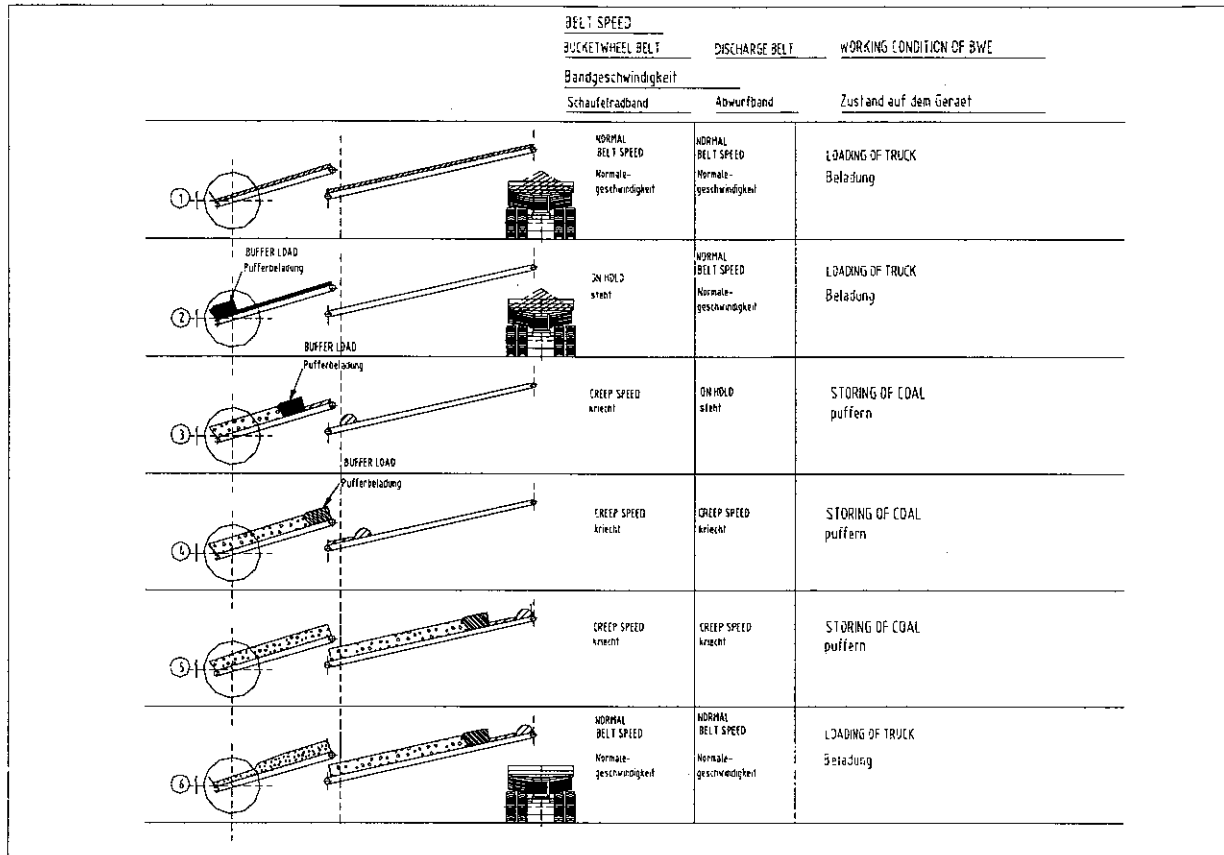


Fig. 17: Conveyor loads over one cycle

During the time required for truck spotting the material mined is stored in the conveyors and chutes. Should the next truck be delayed, the slewing motion is simply interrupted whilst the wheel keeps turning. Thus the BWE-system remains ready in anticipation of the arrival of the delayed truck. By this way the truck fleet is optimally utilized and the loading time minimized.

Shortly before the truck is loaded, the bucket wheel belt stops, while the material on the discharge belt is unloaded into the truck. In the meantime the bucket wheel with the slewable superstructure is constantly digging. So an excess charge on the conveyor of the receiving boom is created (fig.17.2). When the discharge belt is unloaded the bucketwheel belt starts moving at creep speed and transports the excess charge to the transfer point. The restload of the bucket wheel belt builds up another excess charge in the feeding chute of the discharge belt, just under the transfer point (fig.17.3).

When the excess charge build up in the feeding chute of the bucket wheel belt reaches the transfer point, the discharge belt is started to run also at creep speed (fig. 17.4). Now both belts are moving at creep speed by storing the material on the belts (fig. 17.5). When the next truck is in place the conveyor speed of both belts is increased to it's maximum speed (fig. 17.6). Due to the increased speed the charge on the conveyor's comes to normal, unless the truck is fully loaded and the process starts again (fig. 17.1).

For realizing the transportation of excess charges on the belts, both belts have fixed liner plates on each side covering the total length of the belts.

4.3 Working scheme / Mining Plan

Detailed investigations have shown, that also coal seams of lower thickness can be dug economically. The seams in the range between 1.0 m and 5.0 m can be dug in one cut, i.e. the efficiency grade of a Bucket Wheel Excavator in this operation is higher than in the normal digging operation, as the machine does not need to adjust the bucketwheel to different heights of benches, but can dig straight ahead.

Considering these investigations the newly developed technique is to cut one constant block in a height of approx. 60 % of the bucketwheel diameter along the whole pit. Then the BWE turns around and digs the next block beside or the next block below.

Selective digging is used, if the thickness is varying or imbedded layers of shale, clay or other materials are found. The operator adjusts the wheel to the surface of the embedded layer to ensure that only the coal is mined without impurities. Depending of the size of the wheel and on the type of teeth used the accuracy of the wheel is in the range of 10 cm.

Digging a thin seam with a high output requires fast relocation of the machine and large areas are excavated within short times.

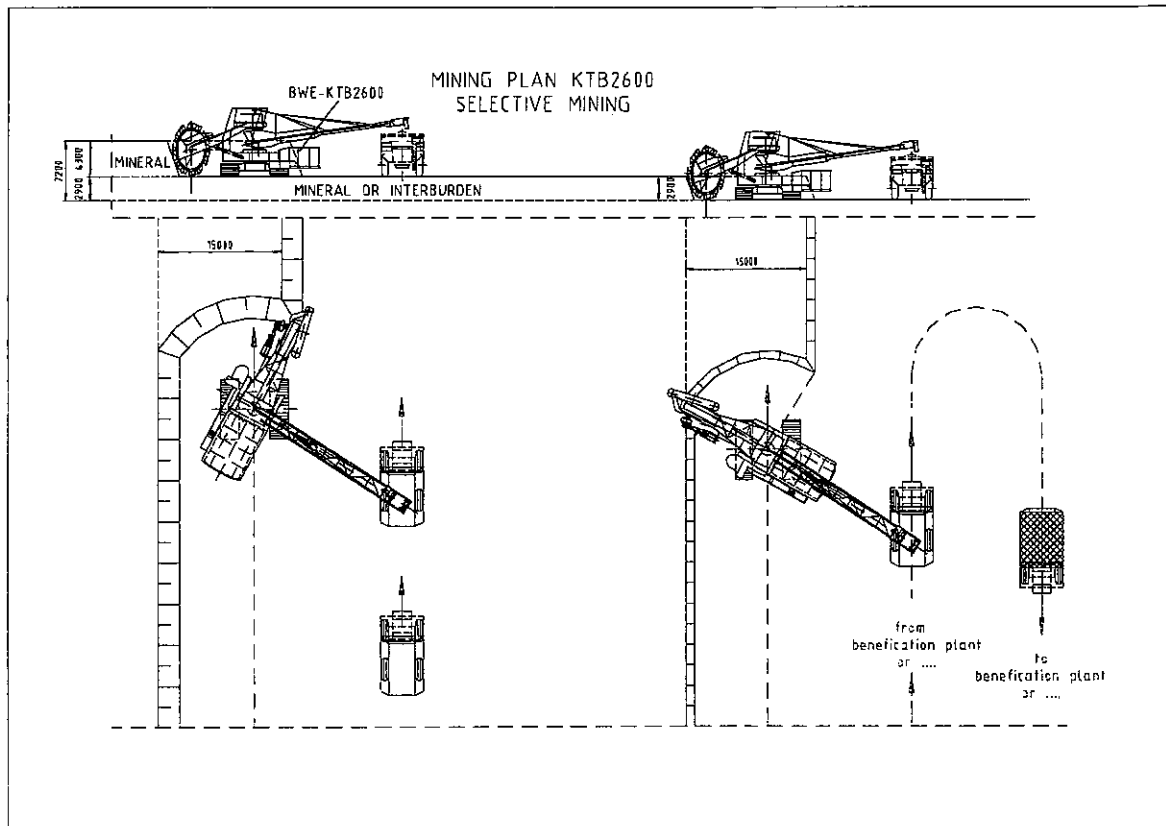


Fig. 18 KTB working plan / surface mining mode

5. Testing of the KTB 500

5.1 Technical concept

The technical concepts of Krupp for the development of the KTB are based on the following main principles, which are nearly identical to the philosophy of the hydraulic excavator technology:

- The customer gets a tested and proven product. The machine is easy to handle, allows maximum mobility for machines of this size and can be erected and started in shortest time once delivered.
- The BWE can be dismantled in collie sizes which allow normal street transport. The smallest version can be handled on a low boy for in mine transportation.
- Erection or dismantling can be done within one week, using in-house personal and a KF supervisor.
- Krupp will offer a high availability guarantee for the machine.

The complete undercarriage system including the turntable used in the KTB series are out of proven machine parts used in construction business. The motor (electric or diesel) is settled in the superstructure together with the hydraulic and the automation system. The above described superstructure can be shipped as one piece.

The modular designed bucket wheel boom allows to chose wheels and motors from the Krupp standard series of motors and wheels to suit the different mining applications. Automation hardware is the same for all machines allowing to adapt more modules on the smaller machines.

Furthermore all KTB bucket wheel excavators can be delivered with the below listed features:

- reduced ground bearing pressure by using different base plates
- micropilot (PC based automated digging process)
- remote control
- laser guided mining (for selective mining and clean working benches)
- video control of the transfer points
- climate control
- heated chutes
- special liners for undisturbed material flow in the chutes
- design for low temperature conditions
- dozer blade
- special paintings for use under aggressive conditions
- conveyor belts for aggressive materials
- special belt cleaners
- water sprinkling system for dusty materials
- etc.

Once again we like to mention that the BWE's of the KTB series are designed by using proved components which are often used in machines all over the world. Undercarriage system, turntable, slewing and belt gear reducers, as well as hydraulic and electric parts are used in the construction business machinery. Mostly produced in huge series. The heart of the BWE the bucket wheel gear reducer will be designed and built only in Lübeck, considering several decades of mechanical background on all kinds and sizes of gear reducers combined with newest design methods and standards.

5.2 Testing of storage mechanism

For verification of the theoretical design work a complete practical testing program of the KTB 500 was started to verify the following main items.

- Determination of maximum load on the conveyors for different material
- Verification of the maximum inclination angle on the belts for full load
- Influence of chute friction on the transportation process
- Verification of the transmission engineering for the proposed working conditions

For testing the following materials were used. Sand sized between 0 - 2 mm and different water contents, gravel sized between 16 - 32 mm and rubble between 0 - 80 mm. These can be seen as typical materials mined with Bucket Wheel Excavators, considering their special properties.

These materials with their typical properties are similar to a large portion of the materials which can be mined with BWE's. Therefore it is possible to transfer the results to materials typically mined with BWE's, such as sandy or gravel overburden, marl, limestone, iron sand, lignite and hard coal.

Test results are as follows:

1. The total theoretical load capacity was reached for each of the tested materials. Maximum distance between bulk materials and the top of the chutes was 120 mm. That equals a haulage cross-section of 0,33 m².
2. The chute friction influences the transport system depending on the material. Using gravel and construction a dynamic angle of repose of 23 degrees was found. The natural angle of repose of these materials is 30° degrees. With sand the dynamic angle of repose was as the natural angle 35 ° degrees.
Furthermore it was recognized that on starting the belt the material in the middle of the belt was moved first, while the material close to the chutes stayed passive for a short time. This expected effect is natural for materials where the friction between the chutes and the material is greater then the inner angle of repose. The process can be characterized in the way that first the material in the middle belt section starts moving creating some space for the outer material to get away from the chutes. This causes a decreasing force on the chutes resulting from the material weight and therefore the resulting friction decreases allowing the material to follow the material flow in the middle. Resulting on this effect a stationary condition is reached, where the forces in the material are slightly higher then the forces between material and the chutes.
3. All tests were made under horizontal, five, ten and fifteen degrees angle of the discharge belt. Hauling and storing of the material was possible under every chosen angle. Especially at the angle of 15° degrees several test were done and no restrictions for hauling and storing were found.
4. Using influentially drives with frequency converter technique on a BWE - belts is an innovation. The tests proved that it works effective and safe.

The tests in Lübeck have shown that using chutes for a higher haulage cross-sections at the relation of 1 : 1 can be used for maximized material transport, even under difficult conditions such as a high haulage angle and high friction.

Considering that the tests were performed with angled chutes of steel we are sure that using vertical chutes and plastic liners will guaranty less friction and that nearly every conveyable material can be handled.

Test results have proven that the KTB is able to handle truck changing times by storing the material on the belts.

More tests will be done in the field, starting in the second half of 1997 at the Profen Mine MIBRAG.

Pictures of the KTB 500 tests are shown in Appendixes A - H.

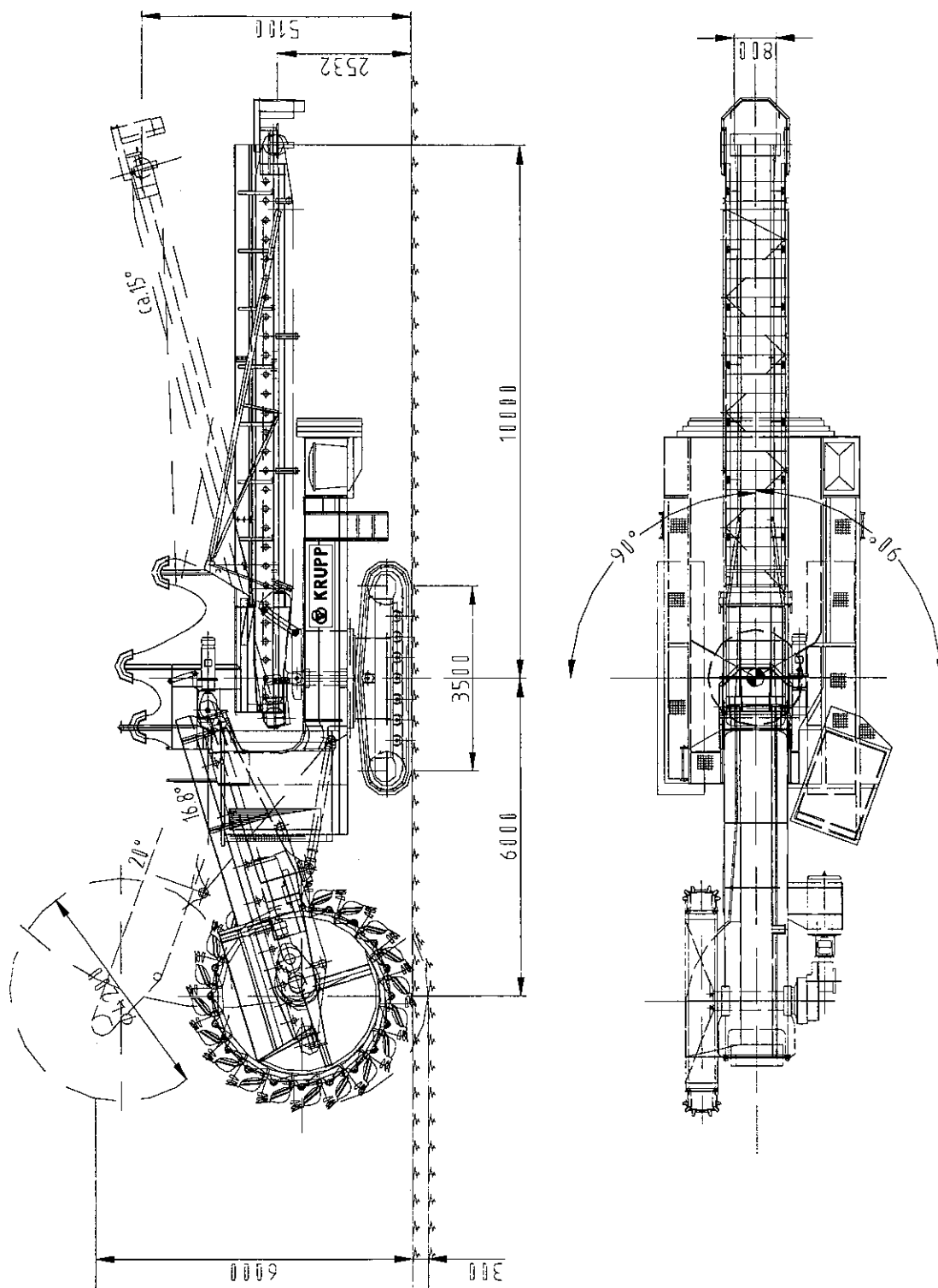


Fig.: 19 Reconstructed KTB 500

The loads on the belts are shown in figure A of the appendix. For better understanding the normal belt loads are shown on the left side.

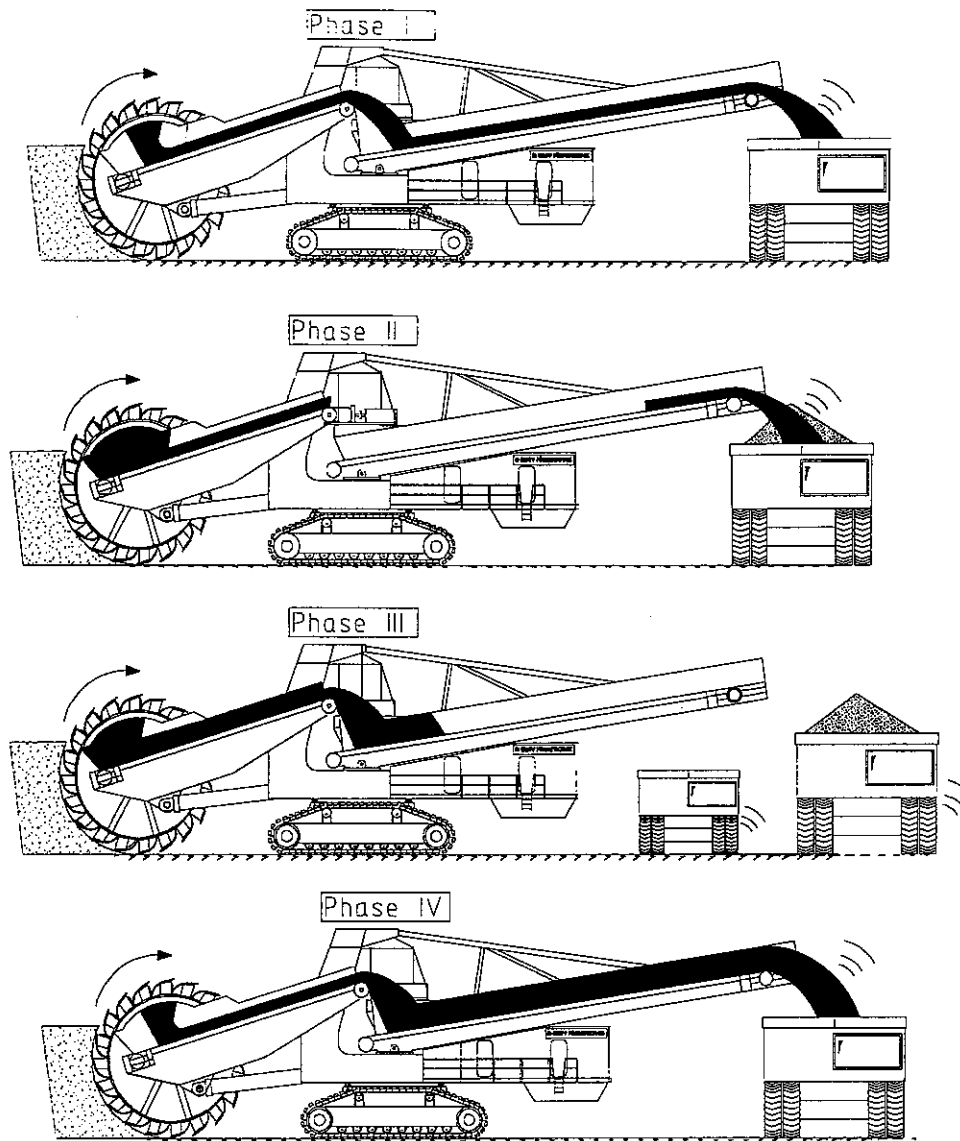


Fig.: 20 Conveyor load cycle of KTB 500

Krupp has recently started to prove this concept under real mining conditions at the Profen mine of MIBRAG. At the meeting we will be able to present more results on the performance of the machine.

6. Fields of application to the BWE-Truck and economical aspects

The new Bucket Wheel Excavator for Truck loading is designed for optimized used in hard coal mines. Therefore the machine is able to handle several different working conditions, as for example

- mining of thin coal seams or layers
- selective mining of coal and embedded layers, e.g. blind coal, clay etc.
- mining of thick coal seams
- mining of inclined coal seams
- loading of trucks for highly flexible and economic operations
- to feed a conveyor system for highly economical operations

Many cost calculations have been made over the years and most miners will be familiar with the way these calculations have to be performed. Anyhow it is always interesting to come back to the reasons why one system is more economic than the other. Considering the basic figures of each

economy cost calculation, we can presume the following advantages by using a Bucket Wheel Excavator for Truck loading,

- moderate capital costs per unit,
- reduced operating costs by dropping of drilling, blasting and crushing,
- reduced operating costs for mineral processing by high grade coal due to selective mining
- the number of trucks which has to be available can be reduced (capital costs), due to reduced spotting times for trucks,
- a higher transport ratio is realized by optimized loading of the trucks,
- reduced labour costs,
- low maintenance and repair costs by use of standard machine parts,
- and low energy and lubrication costs.

Specific operating cost per ton using a Standard Bucket Wheel Excavator with less than 1 \$ / m³ are favorably unbeaten by any other system on the mining market. While using the BWE for hard coal applications industry can fulfill their needs for a cost economic mining system with increased flexibility and mobility.

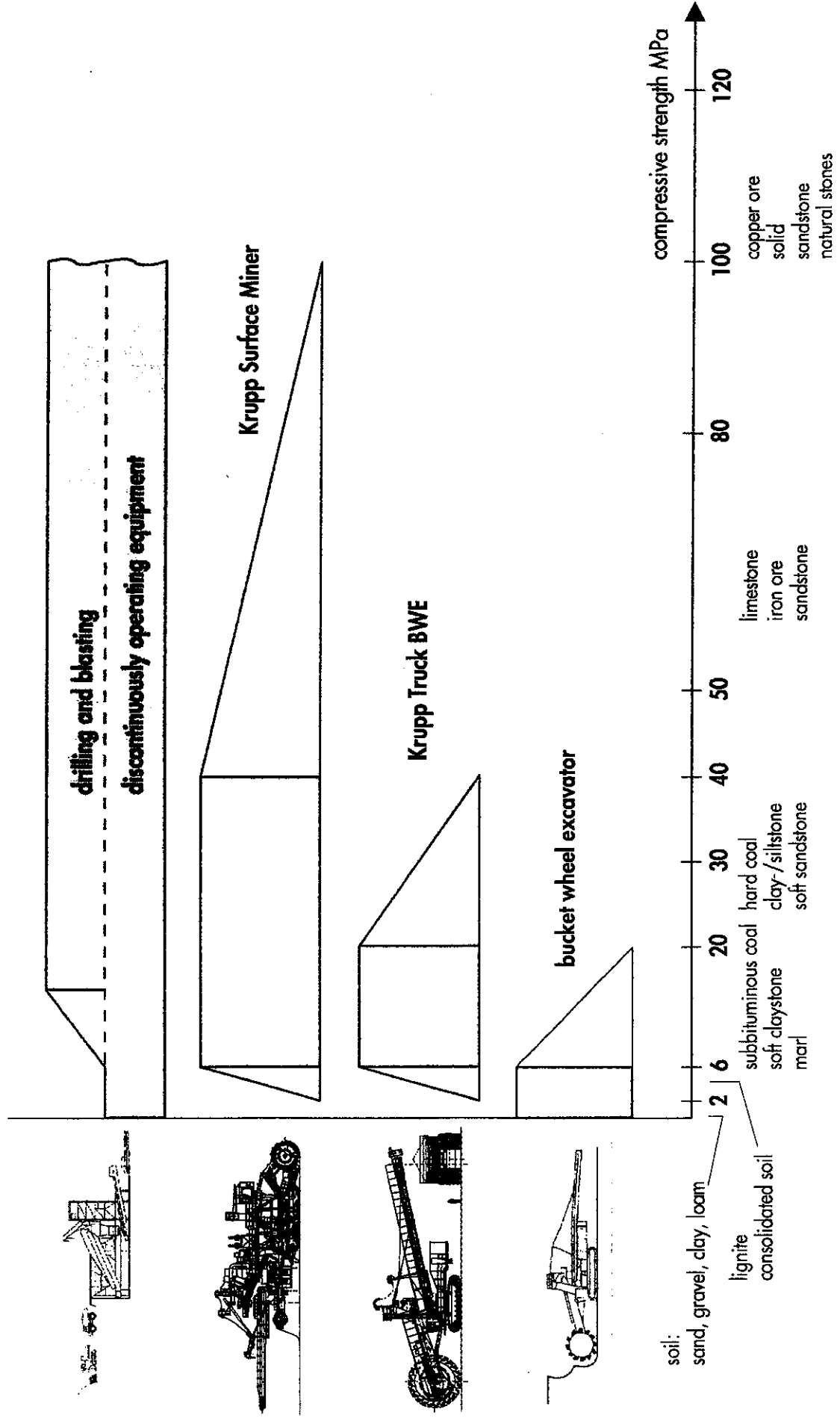
6. Outlook

So to summarize: The high power of the new wheel, the new and patented wheel design with integrated buckets and the correct digging technique. All this three points together assure that the new BWE's can dig hard material.

By storing the mineral on the Mining System, the new Krupp Standard Bucket Wheel Excavator is most economical able to load the existing trucks. Furthermore additional cost savings are to be expected by combining these automated technique with automated / GPS guided trucks.

With the increased ability for digging inclined layers and the higher mobility the machine fulfills the needs for a mobile equipment, when working on changing sites and changing conditions in the mine.

Open Pit Mining Technologies



APPENDIX Fig. 1

APPENDIX A



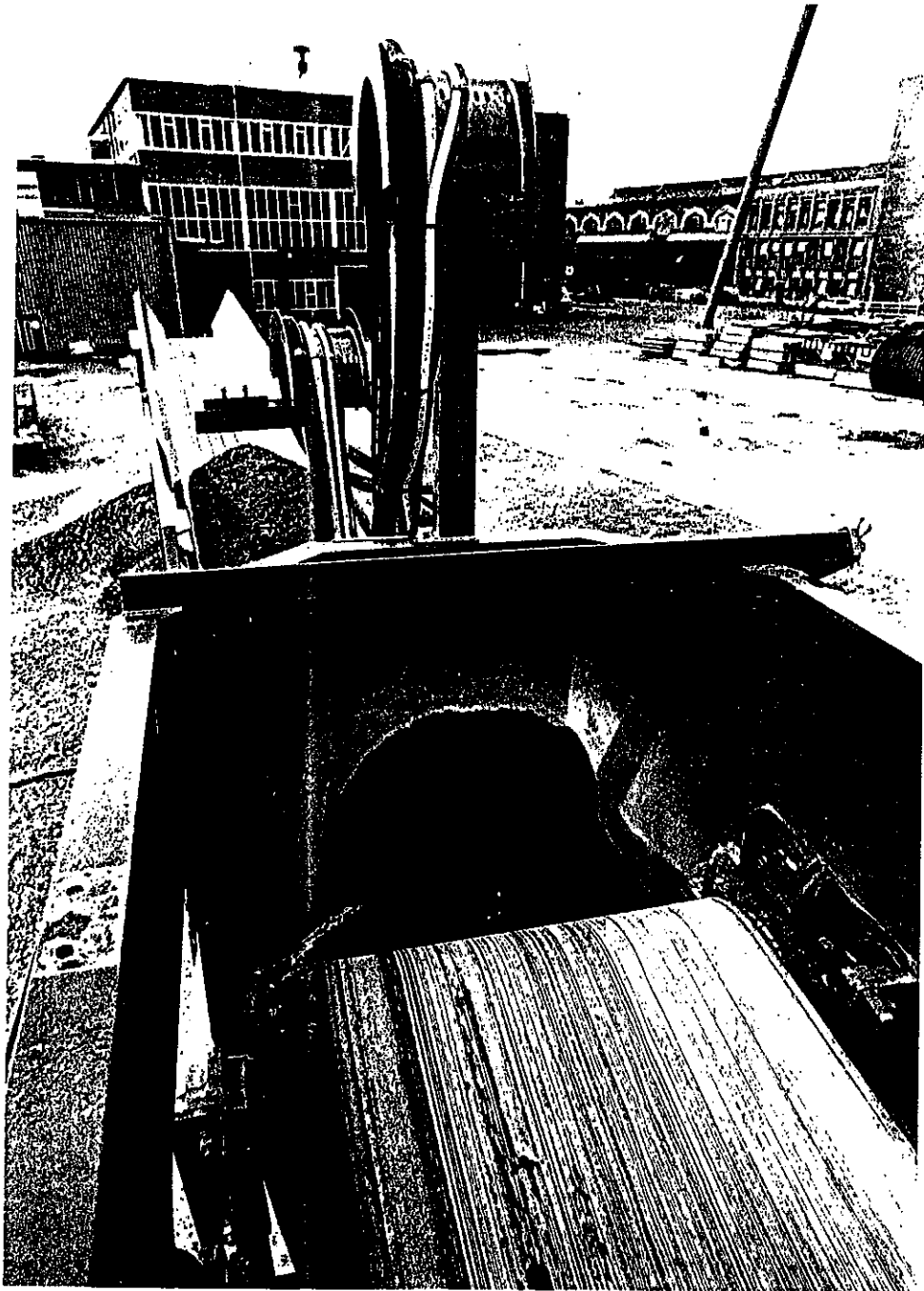
APPENDIX B



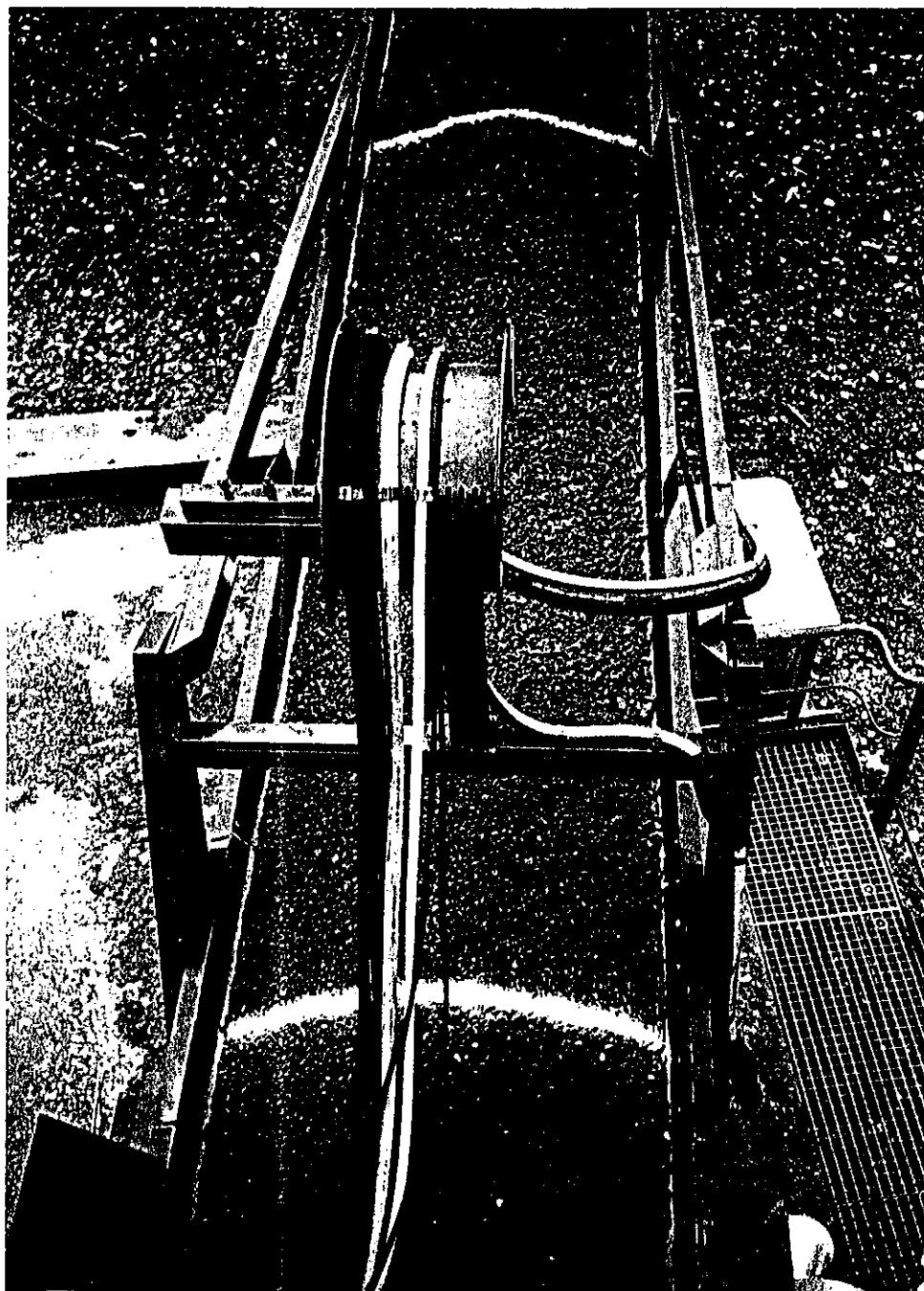
APPENDIX C



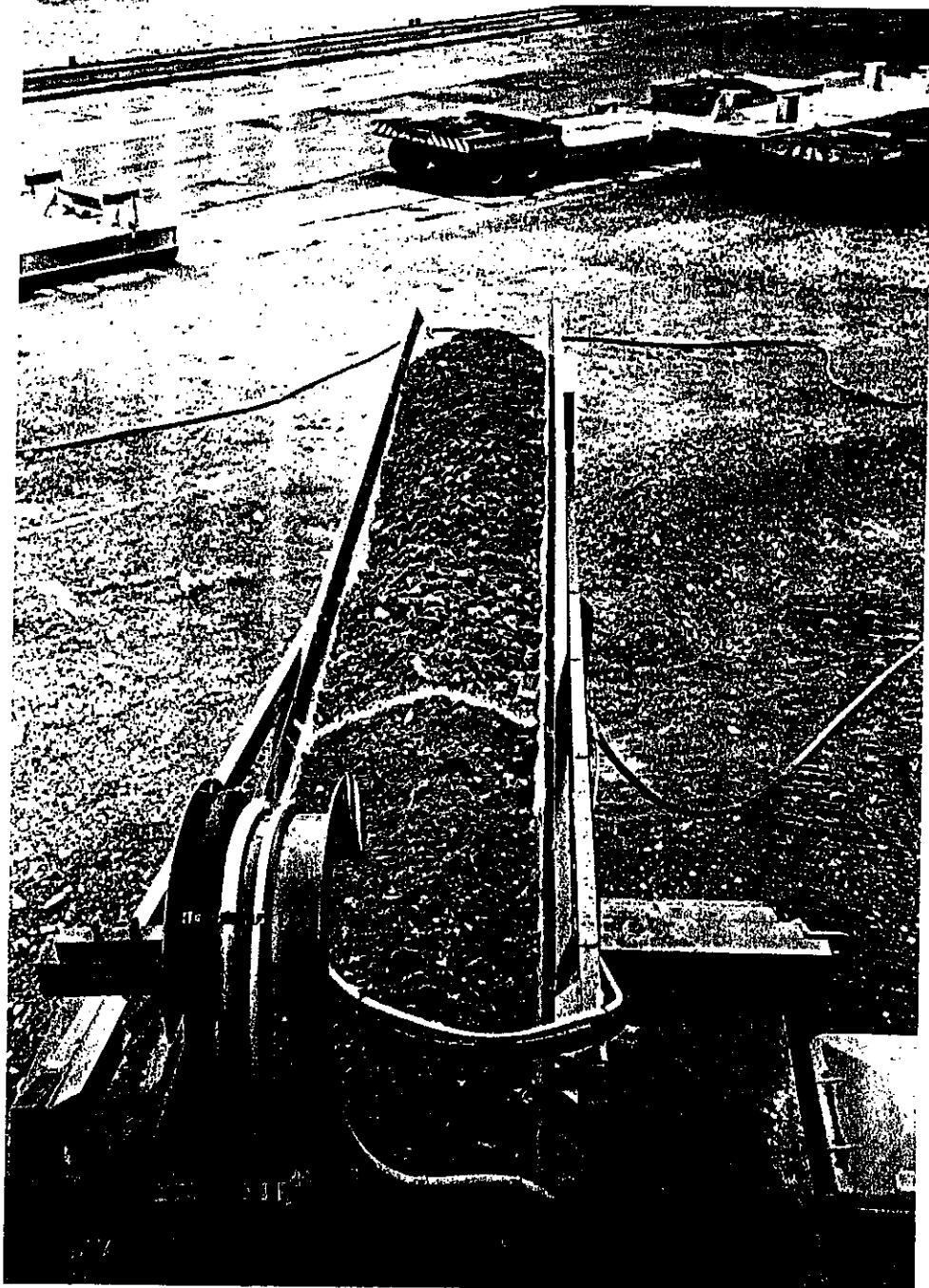
APPENDIX D



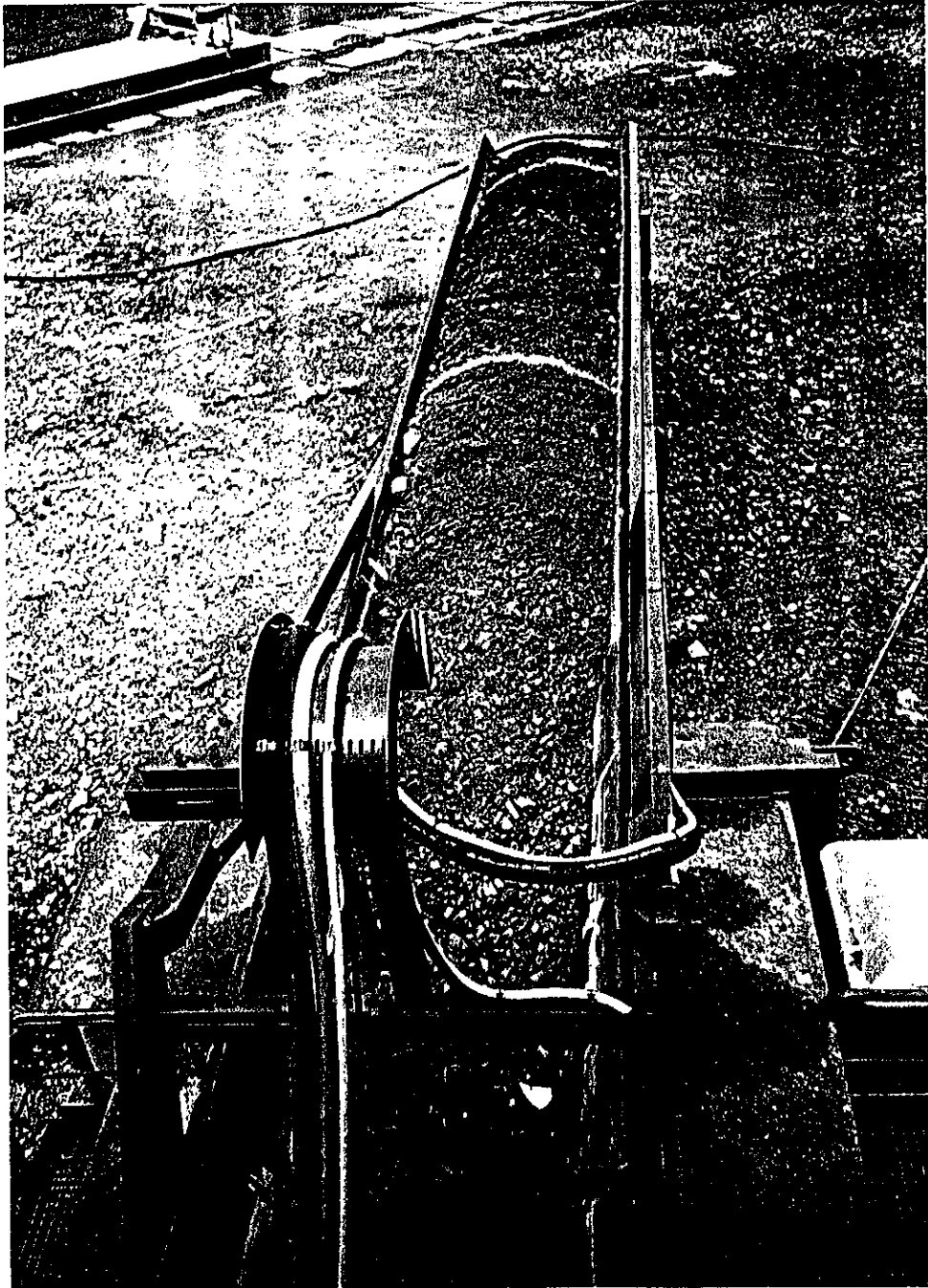
APPENDIX E



APPENDIX F



APPENDIX G



APPENDIX H

