The Development of Bucket Wheel Excavators During the Last Fifty Years

Walter Durst, Germany

Summary

This article reviews the important development steps in the manufacture of bucket wheel excavators during the past 50 years. New developments and technical improvements in the areas of crawler drives, slewing gear, the bucket wheel, and the conveyor belt of the wheel boom are presented in detail. A section is devoted to the safety equipment of these machines. Finally, the author describes special applications of bucket wheel excavators in Canadian open pit oil sand mines, in chalk mines, in various open pits in Germany and other countries, as well as the construction of the Chasma-Jehlum Canal in Pakistan.

1. Introduction

The development of open pit mining over the past 50 years made it possible to mine economically raw materials from ever increasing depths. A prerequisite for this is the capability of stripping and dumping larger and larger masses of overburden at reasonable costs.

Open pit mining technology gave impulses for the development of suitable equipment for digging, dumping and transporting large masses, overburden as well as the pay mineral itself. This development took place simultaneously for the so-called conventional (discontinuous) mining equipment such as front end loaders, shovels and draglines as winning machines with heavy trucks as transport units, and for the continuously operating equipment such as bucket wheel and bucket chain excavators as digging elements, conveyor lines for the transport of the mined material, and spreaders for dumping the overburden.

Conventional equipment is primarily used when mining pay zones which are not covered with high overburden depths and where the overburden can be overthrown directly across the stripped raw materials into the mined out zones of the pit.

In Germany, where the overburden has always been of considerable thickness and, therefore, direct overthrow of the overburden was not possible, the application of conventional equipment did not appear to promise any economic success. Therefore, the development of continuously working equipment, principally of bucket wheel excavators, was accelerated.

Fig. 1 shows the first bucket wheel excavator, built by O&K in 1933, in comparison with the biggest excavator in the world built by O&K with a daily output of 240,000 m³ (bank) which was put into operation at the end of the seventies. This makes the development in size apparent of equipment built during the last fifty years. The development of a great number of constructional elements and their combination into a serviceable whole was the consequence of such considerable increases in size.

These individual developments were mainly carried out by the manufacturers of continuously working equipment, and often completely new methods had to be adopted for which no empirical knowledge existed. Therefore, one can say that genuine pioneer work was done in technical development. It must be emphasized that responsibility for the feasibility of these developments initially had to be borne by individual firms (maker and user). Substantiated by experience in operation, these developments became commonly accepted in equipment technology.

Since it was founded, the firm of O&K was concerned with the problem of mining masses and has played an important role in the technical development of bucket wheel excavators since 1933. At that time, the Lübeck works of this company operated under the name of Lübecker Maschinenbau Gesellschaft (LMG).

Here, the excavators were built which were so successfully used for the construction of the Kiel Canal, called the Kaiser-Wilhelm Canal at that time. LMG had a team of competent engineers for the development in all fields of technology. Many details for the construction of bucket wheel excavators which are taken for granted were invented in the technical office and used in the new machines. They often proved to be correct and useful. In the following, some of these developments are described which originated from the Lübeck works.

2. Crawler Travel Gears

When using mining equipment in open pits, it was soon found that the original rail travel gear which was taken over from older mining machines caused difficulties in operation. Therefore, the step was taken to equip the machines with crawler travel mechanisms.

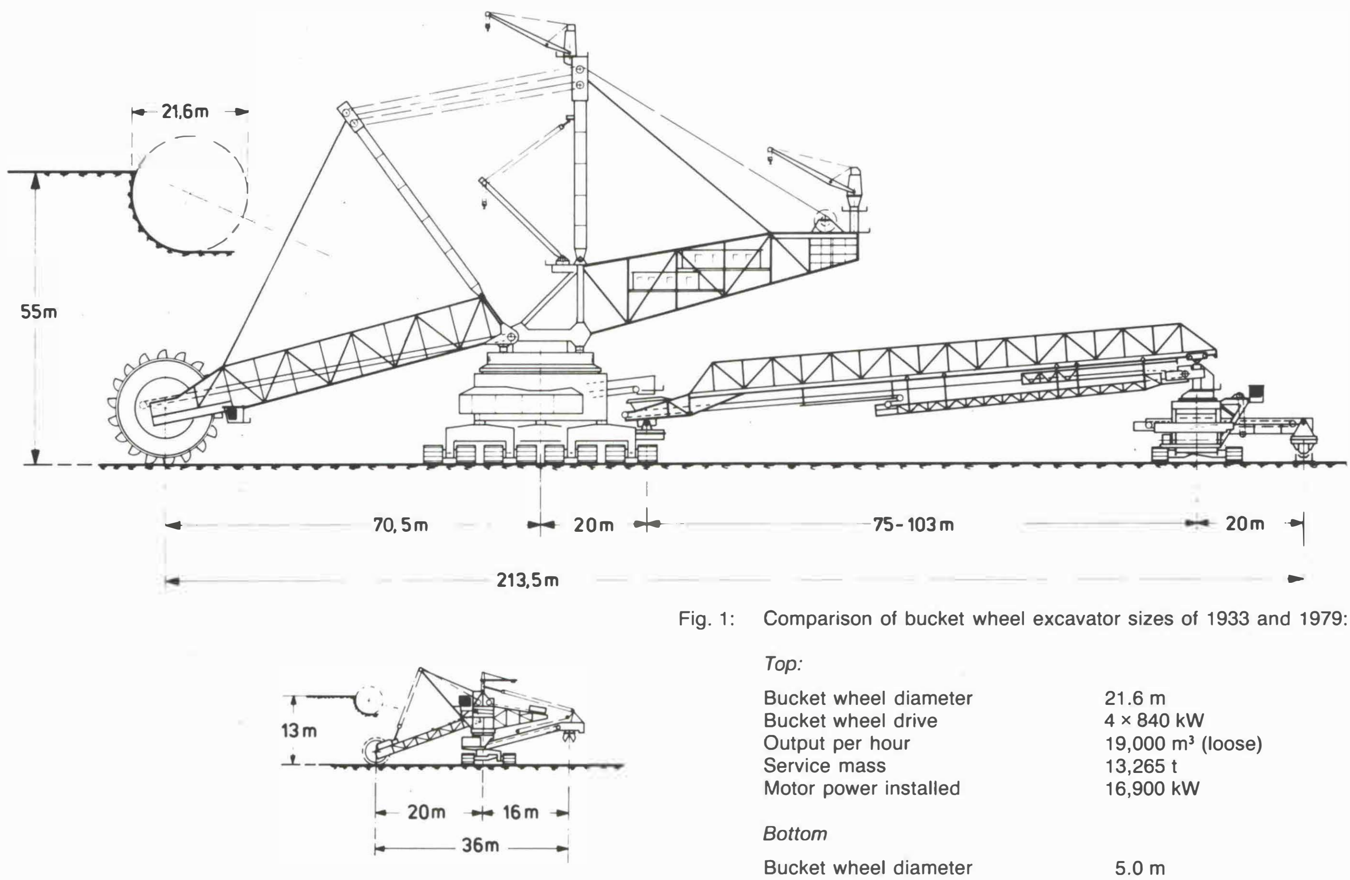


Fig. 1: Comparison of bucket wheel excavator sizes of 1933 and 1979:

Top:

Bucket wheel diameter	21.6 m
Bucket wheel drive	4 × 840 kW
Output per hour	19,000 m³ (loose)
Service mass	13,265 t
Motor power installed	16,900 kW

Bottom

Bucket wheel diameter	5.0 m
Bucket wheel drive	74 kW
Output per hour	750 m³ (loose)
Service mass	352 t
Motor power installed	300 kW

Such crawler travel gear had already been known in connection with open-cut equipment since 1933. The first big machine travelling on two crawler chains was a Dragline built by Bucyrus & Co., Milwaukee. German manufacturers, too, already had bucket wheel excavators in open pits travelling on two crawlers. However, in these machines the crawler frames were rigidly connected to the substructure of the equipment, and the individual travel wheels in the crawler frame which transmit the load to the track plates were not equalized. Owing to this, the vertical gravity load was unevenly distributed over the travel wheels. This travel gear was known from tanks.

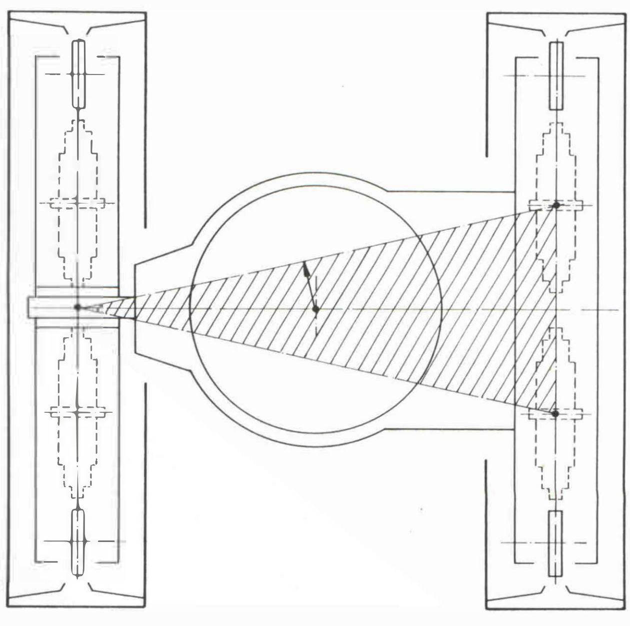
In open-cut operations, however, this travel gear proved to be unsuitable for the application, as due to unevenness in the track level, large movements of the whole machine are induced. Here, crawler travel gear was required which could adapt itself to the unevenness of the ground without having serious effects on the whole machine.

It was also necessary to transfer the increasingly growing vertical load in a statically defined way on to the travel wheels to avoid severe overloading of the different travel wheels.

The requirements first resulted in one of the two crawlers being fastened to the substructure in pendulum fashion, and the second crawler frame rigidly connected to the substructure as before. The travel wheels were supported in equalizers and in this way provided statically determined support of the vertical load (Fig. 2).

This design, however, still had several disadvantages in operation. The inclination of the whole machine was still determined by the inclination of the fixed crawler, so that as a result of unevenness of the track level on the fixed crawler side, the whole machine could still make big movements, although due to the equalized travel wheels an improvement over the completely rigid travel gear had been achieved.

Fig. 2: Two-crawler travel gear with one pendular crawler.



With this crawler design, the overturning edge of the crawler travel gear was very near the slewing axis of the superstructure, so that it became problematic to maintain safety against overturning. The movements of the superstructure, induced by the fixed crawler additionally resulted in further unfavourable shifting of the centre of gravity and reduction of the overturning safety. Consequently, a new form of fastening the crawlers to the substructure was developed, i. e., both crawlers were fastened to the substructure in a way to allow self-alignment, and the third supporting point for the substructure was supported on a transverse girder arranged between the two crawler frames (Fig. 3).

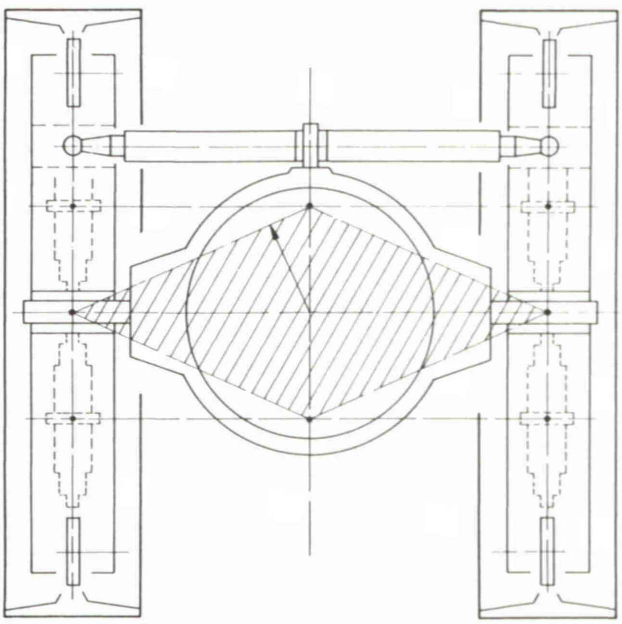


Fig. 3: Two-crawler travel gear with two pendular crawlers.

Owing to this type of support, the distance of the overturning edge of the crawler travel gear from the slewing centre of the machine was increased. In this way, the overturning safety of the machine relative to the crawler travel gear increased as compared with the design in Fig. 2. In addition, the effect of the inclinations of the crawler frames on the whole machine due to unevenness of the ground is halved, and the reduced centre of gravity shifting of the superstructure resulting from this further increased the overturning safety of the superstructure. For this arrangement of crawlers, a patent was applied for by O&K at the German patent office in 1953. The patent was granted under the German patent No. 1002696. In addition, this patent right was applied for and granted in various other countries of the world. Later, several two-crawler machines were also equipped by other makers with this crawler arrangement which proved satisfactory in operation and on bigger machines entirely replaced the crawler arrangement (Fig. 2).

When using bucket wheel excavators in open-cuts, it was realized at an early stage that travel gears of such machines must be capable of maintaining a certain preselected curve radius.

As early as 1936, O&K developed and built the first steerable three-crawler travel gear where the two crawlers on the two-supporting-point side could be slewed by means of a spindle in such a way that the travel movement developed along a given curve radius (Fig. 4).

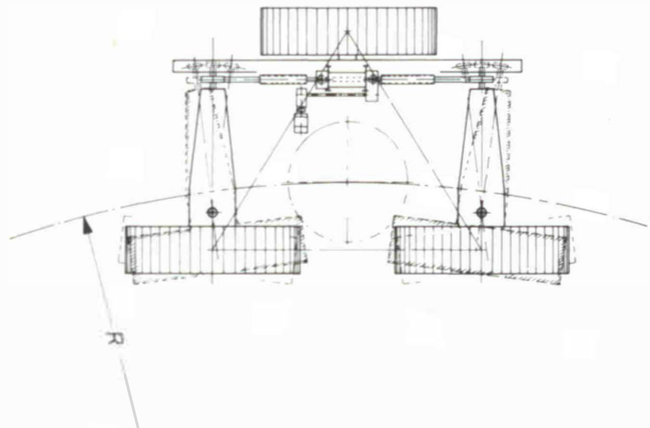


Fig. 4: Steerable three-crawler travel gear.

The development of larger and larger units (dimensions and outputs) resulted also in big increases in weight. Owing to this, the gravity load on the crawler travel gear increased as well. Experience with machines already in service showed that the average ground bearing pressure under the crawlers should not exceed the value of 150 kPa (15 N cm^{-2}). In order to maintain this value, more than three crawler chains were required. Initially 6, later 12 crawler chains were required to transfer the large loads to the ground. Track plates with a width of up to 3.70 m were built. Recently, however, a travel gear has been developed for a giant machine with a daily output of 130,000 m^3 (bank) whose service mass corresponds approximately to that of the machines with a daily output of 110,000 m^3 (bank), and this has only six instead of the twelve crawler chains normally used for such machines until now. For the first time, track plates with a width of 4.5 cm are used. This is a further step in the development of crawler travel gear.

With the increasing loads and the greater number of crawler chains, the forces for crawler steering also increased greatly and, therefore, the design of the steering spindle became more problematic, in particular with regard to lubrication and wear. O&K were the first makers of bucket wheel excavators to find new ways here. They used a hydraulic cylinder as the steering element instead of the conventional steering spindle. This hydraulic cylinder has essential advantages in providing the necessary forces and their limitation but also with regard to wear and maintenance. Fig. 5 shows the design of the steering of a six-crawler travel gear with a steering spindle for a steering force of 3,820 kN. The weight of this steering spindle is 16.4 t.

Fig. 6 shows the same travel gear with a hydraulic cylinder as the steering element. The total weight of this steering mechanism is no more than 9.5 t. Hydraulic cylinders were used for the bucket wheel excavators winning oil sands in the Canadian oil sand area operating under very severe climatic conditions where they have proved their worth for many years in operation and also on the biggest bucket wheel excavators built in recent years which travel on twelve crawler chains. A force of 10,000 kN is required to be exerted by this cylinder. The greatest length in the ex-

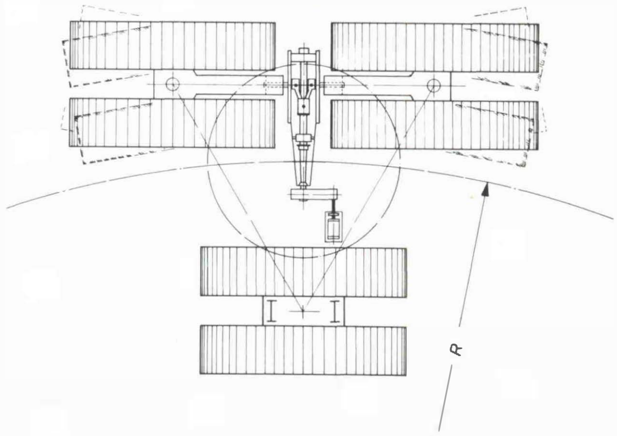


Fig. 5: Six-crawler travel gear with steering.

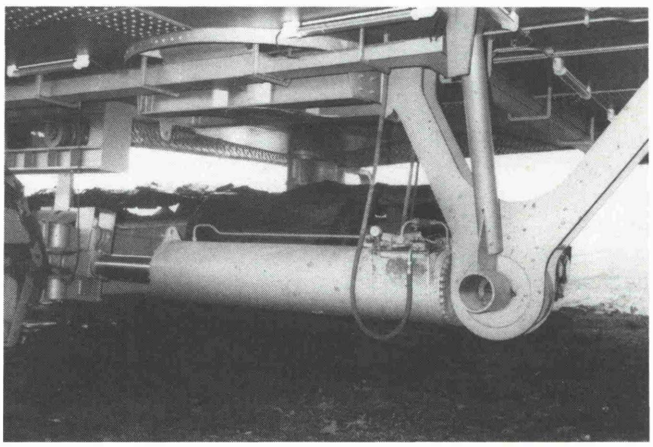


Fig. 6: Hydraulic steering cylinder for a six-crawler travel gear.

tended condition is 13.6 m, the highest pressure in the cylinder is 17 MPa (170 bar). Cylinders of this size, too, have been working satisfactorily now for several years. Owing to the good experience with hydraulic crawler steering, the hydraulic steering cylinder for the crawler travel gear is a component which is given preference.

3. Slewing Gear

During operation, the slewable superstructure of a bucket wheel excavator is slewed continually relative to the substructure. Therefore, an element has to be provided between the two parts of the machine which allows easy slewing without being subject to heavy wear.

For this purpose, a ball bearing slewing rim is used which is capable of satisfactorily transferring the vertical loads as well as the horizontal forces occurring during operating from the superstructure to the substructure.

With increasing machine size, the diameter of these ball bearings also increased. The largest machines in operation have ball bearing slewing rims with an average diameter of 20 m. The required minimum diameter of such a ball bearing results from the requirement of the overturning safety of the superstructure relative to the ball race still having to be ensured even under the most unfavourable loads. Another reason for selecting the smallest possible ball bearing diameter is that bigger ball bearing slewing rim diameters have unfavourable effects on other dimensions of the machine and its total weight. From the vertical load and its centre of gravity relative to the ball bearing, the biggest load acting on a ball in the ball bearing can be determined.

To get information on the behaviour of ball bearings under operating conditions, rolling tests were already carried out at O&K in the years 1957 to 1963 for which the dimensions of the balls and ball races were so selected that they were close to the dimensions of the ball races built up to that time.

In the course of development of the largest bucket wheel excavators with ball bearing diameters of 20 m and ball diameters of 320 mm, further rolling tests were carried out at the Technical University Hannover and at O&K, which in particular, rendered information on the material to be used for the ball races. These tests were carried out during the years 1971 and 1972. In both test series, various material qualities for the races were tested. In both cases, the tests showed that high-alloy steels and materials of very high natural hardness failed earlier than low-alloy and tough materials which have greater adaptability and higher resistance against local and frequently recurring stress peaks. From these test series, important information for the manufacture of ball races was obtained which is valuable for the practical operation of all bucket wheel excavators. From the rolling tests as well as practical experience obtained from ball races already built, it becomes apparent that the maximum ball gravity load during operation must not exceed a certain value if the service life of a ball race is to reach an adequate value. The resulting reference value was:

maximum gravity load of a ball — P_{max} (N)
ball diameter — d (mm)

$$k = P_{max} \times d^{-2} = 4 \text{ MPa}$$

It was no longer possible to maintain this maximum permissible ball load with the heavy superstructures of giant machines with a single-race ball bearing, Therefore, as long as twenty years ago, a start was made in building such machines with double races (Fig. 7).

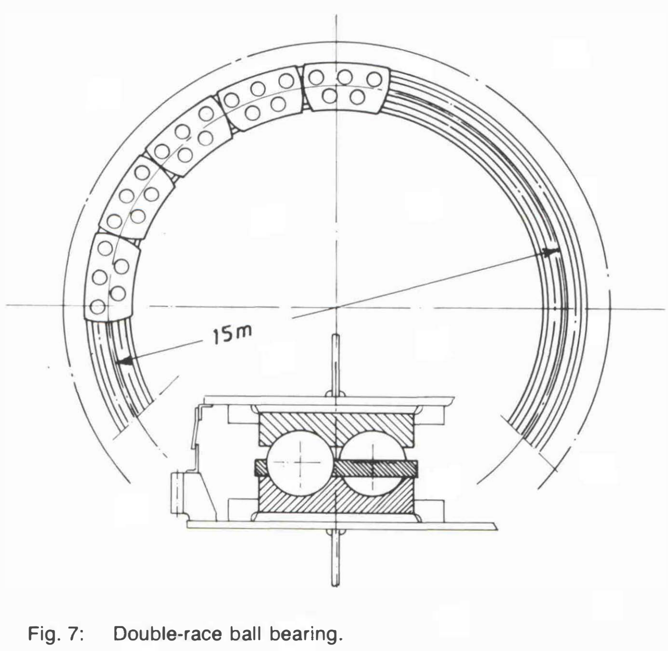


Fig. 7: Double-race ball bearing.

As these first double-row ball races gave good results in operation, the first series of giant machines was equipped with these. These double-row ball races with a diameter of 15 m were installed in two giant machines which went into service in 1959.

4. Bucket Wheel

The development of the cell-less bucket wheel was also partly carried out by O&K. As far back as 1954, the first small bucket wheel excavator with a daily output of 8,000 m^3 (bank) with a cell-less bucket wheel went into operation, and in 1958 the first giant machine with a daily output of 110,000 m^3 bank and a cell-less bucket wheel started work in the Rhineland brown coal area (Fig. 8).

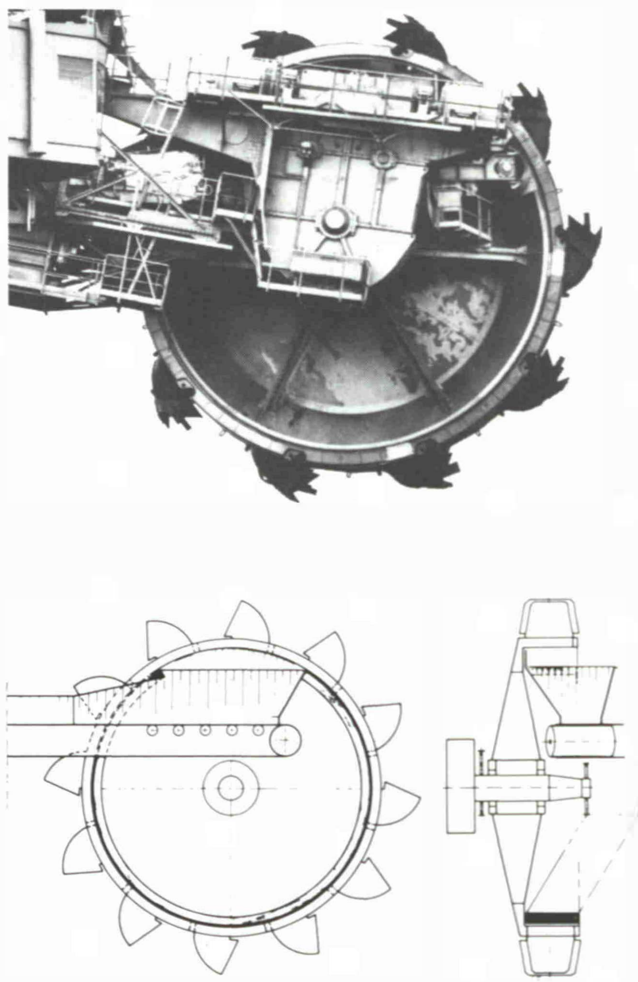


Fig. 8: Cell-less bucket wheel.

To enable the cut material in a cell-less bucket wheel to be properly transferred from the buckets on to the belt in the bucket wheel boom, the bucket wheel has to be suitably arranged. From its optimum cutting position, i. e., its position in a plane which goes through the slewing axis of the superstructure, it has to be slewed horizontally as well as vertically. This results, however, in different cutting conditions for both slewing directions.

As long as the material to be cut is soft and homogeneous, this does not involve any serious disadvantages. With hard materials, however, these differences in the cutting conditions have a very disadvantageous effect. Therefore, for applications of bucket wheel excavators in hard soils, the bucket wheel has been so arranged that the plane of the bucket wheel goes through the slewing axis of the slewable superstructure. In this way, the most favourable position for cutting is achieved. However, with this arrangement the belt in the bucket wheel boom can no longer be taken into the bucket wheel. For transfer to the belt of the material cut by the buckets an additional conveying element, the so-called rotary plate, has to be installed (Fig. 9).

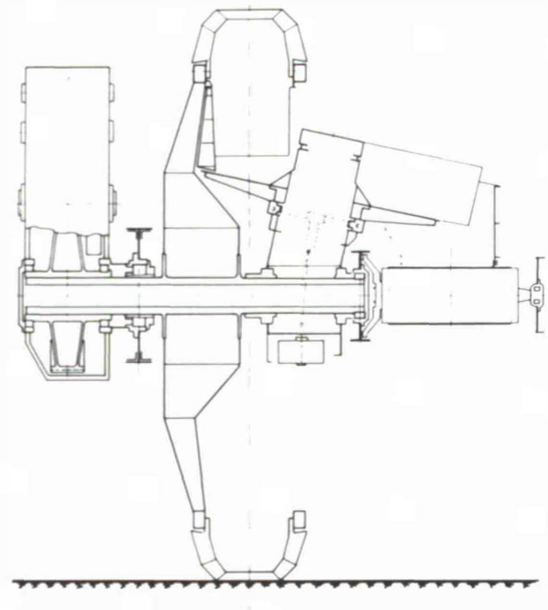


Fig. 9: Cell-less bucket wheel rotary plate.

This design solution has given satisfactory service for many years in machines operating in the open-cut Neyveli, India, in hard sandstone and in the two bucket wheel excavators operating in oil sand in Canada. When developing the giant machines for the Rhineland brown coal area, the ring space under the buckets was enlarged, i. e., so-called half cell provided; in 1963 a giant machine built according to this principle with a daily output of 110,000 m^3 (bank) was put into service.

5. Conveying Path

Experience in operation with elevating belt conveyors had shown that the inclination of a conveyor should not be steeper than 18° if trouble in operation was to be avoided. However, with this belt inclination, it was almost impossible to reach substantial cutting depths below track level. Nevertheless, during a certain development phase, it was hoped that greater cutting depths below track level would bring advantages in equipment application and also for operational planning.

In an endeavour to find suitable solutions which would permit the material to be transported even along steeper belts, a second belt, the so-called cover belt, was arranged above the conveyor. The material was held by means of this cover belt and could, thus, be held even on inclinations up to 30°. As far back as 1954 O&K ascertained the feasibility of such "elevating belt conveyors" in a test set-up (Fig. 10). The results of these tests formed the basis for the designs used on bucket wheel excavators later on.

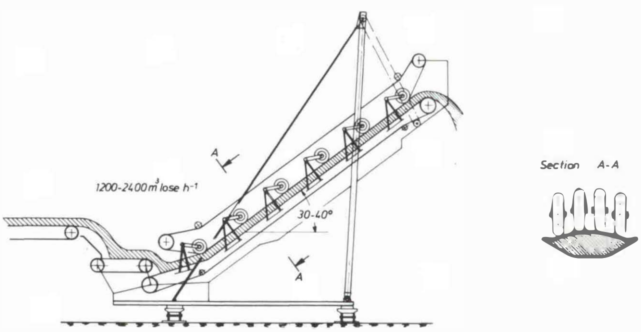


Fig. 10: Material transport on elevating belt with cover belt.

A giant machine with 110,000 m³ (bank) daily output, equipped with elevating belt conveyor equipment, was put into service in the open-cut Fortuna in 1958. The elevating belt conveyor installed in this machine met the demands placed upon it. However, as the open-cut technique advanced still further, big deep-cuts were not used any more and, therefore, elevating belt conveyors were no longer necessary. They were taken off one after the other.

6. Safety Equipment

To make it possible to work with bucket wheel excavators without any greater downtimes, protection devices against overloads are needed for certain drives. For a long time, the LMG catch coupling was an effective overload protection on the different drives. For this design, a German patent was granted in 1938 (Fig. 11). With this coupling, the input step was fixed against the power take-off step by means of a catch which is pressed into a recess by spring load. If the circumferential force at the catch rose above a certain value, the spring load which pressed the catch into the recess was overcome and the catch was forced out. Owing to this, power input and take-off steps were separated. Disengagement of the catch could then be used as signal for switching the drive off.

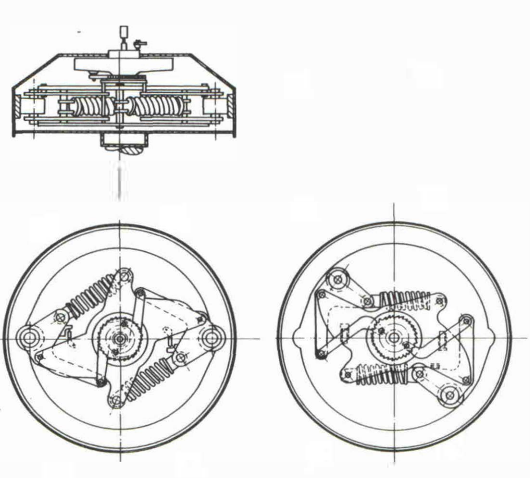


Fig. 11: Overload protection, LMG catch coupling.

When the design of the first giant excavator with a daily output of 100,000 m³ (bank) was developed during 1953 and 1954, the first genuine 2-rope suspension for the bucket wheel boom was engineered and built (Fig. 12). For the first time, rope tension measuring devices were used for the free rope end suspensions which measured the force acting upon the respective hoisting rope, so that the hoisting forces of the bucket wheel boom could be supervised and by suitable tensioning devices could be distributed equally between both hoisting ropes (Fig. 13). At the same time, the development of this machine provided for the support of the superstructure above the turntable in rocker joints (Fig. 14). Owing to this type of support, ex-

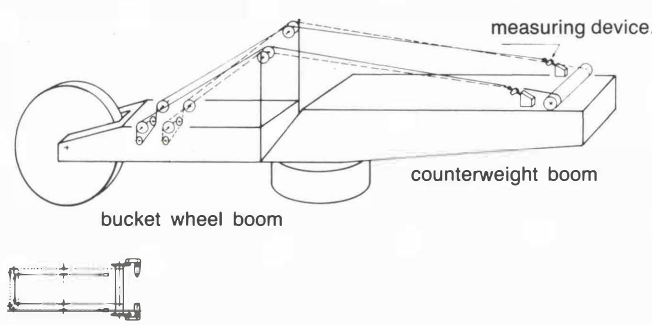


Fig. 12: Two-rope suspension for bucket wheel boom

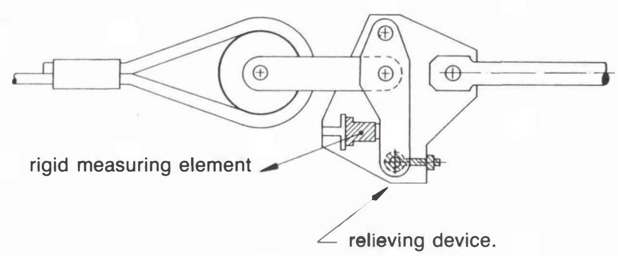


Fig. 13: Rope tension measuring device

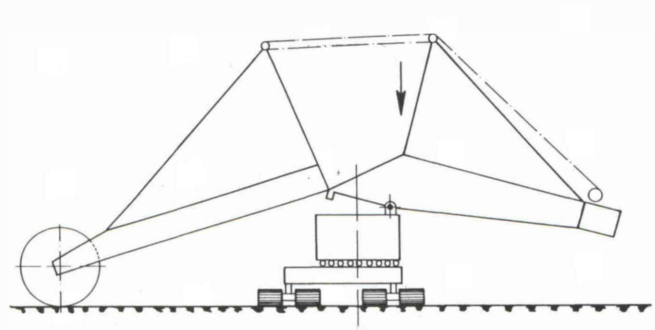


Fig. 14: Superstructure support in the tilting joints.

traordinary forces which can result from burying the bucket wheel or putting it down on the batter, can be intercepted without any overdue stresses on the supporting structure of the superstructure. When the bucket wheel is buried, the superstructure lifts itself from the joints on the ballast side and inclines so far that the bucket wheel rests on the batter. If the bucket wheel lies down on the batter, the supersturcture lifts off the rocking joints on the bucket wheel side. In both cases, lifting out of the rocker joints is indicated. At the same time, the hoisting winch and other drives are switched off. Suitable measures then have to be taken by the responsible supervising person to lower the superstructure again on to the joints.

Nearly all giant machines in the Rhineland brown coal area are equipped with these rocker joints which on several occasions have already contributed towards preventing more serious damage to the machine. Due to the good experience with the rocker joints, giant machines outside Germany were also equipped in this way.

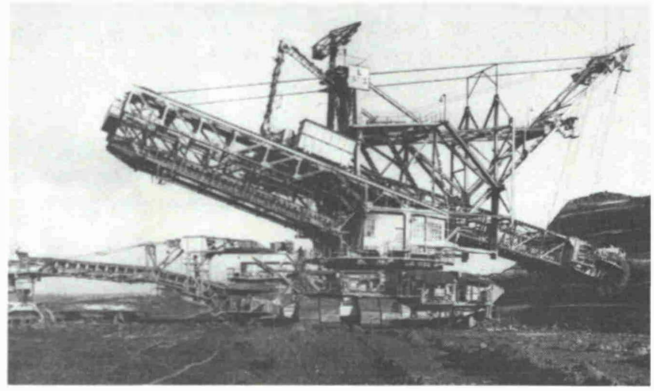


Fig. 15: Bucket wheel excavator in a Polish open-cut.

7. Development of the Machines Themselves

In 1933, O&K built their first bucket wheel excavator with a service mass of 360 t. This machine was put into service in the German open-cut Bitterfeld in 1934. In 1936, a bucket wheel excavator with a service mass of 1,270 t and 800 kW total installed motor power was delivered to a Polish open-pit. This machine is still working today (Fig. 15).

At the end of the thirties, O&K started the development of the first giant excavator with a daily output of 30,000 m³ (bank) for the central German brown coal area. This unit was designed for an hourly output of 1,500 m³ (bank) and was intended to have a service mass of 5,900 t at a total motor power installed of 5,400 kW. Erection was started at the middle of the forties, however, by the end of the war, erection had only got as far as the turntable.

At the end of the forties, it was possible to foresee that the seams near the surface would soon be exhausted in the Rhineland brown coal area and, therefore, the coal at greater depths would have to be exploited. This required handling of huge masses of overburden. Mining planning envisaged machines for this capable of mining 100,000 m³ (bank) per day. In 1952, O&K were given the contract by Rheinische Aktiengesellschaft für Braunkohlenbergbau und Brikettfabrikation (as they were called at that time) to build such a machine.

This unit which was the first of a series of giant machines with a daily output of 100,000 m³ (bank) went into service in the open-cut Garsdorf as early as 1955 (Fig. 16). Right from the beginning, this machine met the requirements stipulated in the contract and is still in operation today.

Fig. 16: Bucket wheel excavator with 100,000 m³ (bank) daily output in the open-pit Fortuna, Garsdorf

Bucket wheel diameter	16 m
Bucket wheel drive	2 × 525 kW
Output per hour	5,830 m³ (loose)
Service mass	5,726 t
Motor power installed	8,900 kW

Until the early seventies, O&K supplied a total of seven giant bucket wheel excavators to the Rhineland brown coal area including one machine with a bucket wheel boom of 100 m length. Participation in the development of a new giant bucket wheel excavator with a daily output of 240,000 ³ (bank) was a matter of course. Rather remarkable is the gear for the bucket wheel of 21.6 m diameter and a drive power of 4 × 840 = 3,360 kW which is shown in Fig. 17.

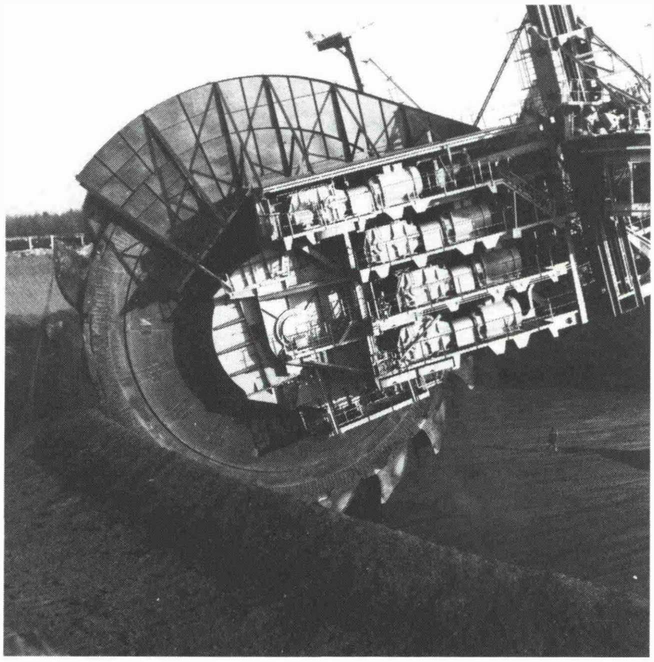


Fig. 17: Bucket wheel of 21.6 m diameter

Bucket wheel drive	4 × 840 kW
Output per hour	19,000 m^3 (loose)
Service mass	13,265 t
Motor power installed	16,900 kW

Apart from these giant machines, O&K also built a series of bucket wheel excavators with a daily output of 60,000 m^3 (bank) and many machines with lower output for various applications all over the world.

Based on the experience with bucket wheel excavators for the most varied applications, these machines were also used for mining hard materials such as, for example, in the brown coal open-cut Neyveli in South India.

There, the first bucket wheel excavators went into operation during the years 1958 to 1965 (Fig. 18). Three further machines which started operating in the years 1979 and 1980 are designed for a hourly output of 2,250 m^3 (bank). In practical operation, they have often considerably exceeded this output. Maximum daily outputs of up to 80,000 m^3 (bank) were reached.

First contacts with Sunoil with a view to exploiting the oil sand fields in Northern Canada go back to the year 1955. After negotiations with the subsidiary of Sunoil, Great Canadian Oilsands Ltd. (GCOS), a decision was taken to use bucket wheel excavators for opening-up the open-pit to the north of Fort McMurray. The contract for the supply of two bucket wheel excavators and two beltwagons was awarded to O&K in 1965. After a building time of less than two years, the machines went into service in 1967. For this equipment, tests were carried out to find suitable structural steel to withstand the high and frequently changing loads at the low temperatures prevailing at the site and which would also allow satisfactory welding. At that time, no so-called cold weather steels were available on the German market. Therefore, the maker of this equipment had to acquire the fundamentals in this field first. These machines have now been operating for about 15 years and have met the demands made on them in every way. This is also due to the thorough preparatory work when selecting materials.

Fig. 18: Bucket wheel excavator in the brown coal area Neyveli/India

Bucket wheel diameter	8.0 m
Bucket wheel drive	650/135 kW
Output per hour	3,570 m^3 (loose)
Service mass	1,336 t
Motor power installed	1,730 kW

After initial difficulties when working with these machines in oil sand frozen to a depth of about 4 m, it was possible — in cooperation with the user's engineers — to bring both machines up to the specified output also during the cold winter months and to supply the extraction plant with a sufficient quantity of oil sand the year round, so that the specified amount of crude oil of 45,000 barrels a day equalling about 7,500 m^3 could be delivered. Based on the good experience with these machines when mining large masses, GCOS ordered a bucket wheel excavator for stripping the overburden above the oil sand. As this overburden is to be dumped in different places which are far apart, a conveyor system cannot be used for transport. The material mined by the excavator has to be loaded on heavy trucks with a capacity of about 130 t each. Therefore, a comparatively long discharge conveyor with a heavy discharge chute is attached to the machine (Fig. 19).

Owing to the long discharge belt with the great mass of the discharge chute attached to its end, the position of the centre of gravity and, therefore, the stability of the machine is considerably affected. Special measures had to be taken concerning the slewing rim between superstructure and substructure as well as the travel gears.

Fig. 19: Bucket wheel excavator in the Canadian oil sand open-cut with long discharge belt and discharge chute

Bucket wheel diameter	12.5 m
Bucket wheel drive	2 × 500 kW
Output per hour	7,865 m^3 (loose)
Service mass	1,813 t
Motor power installed	3,000 kW

An ordinary ball bearing which cannot transmit any tensional forces between supersturcture and substructure could not be considered for this machine. A roller bearing had to be chosen, which was capable of transferring the tensional forces occurring between superstructure and substructure (Fig. 20).

As under extraordinary operating conditions, the position of the centre of gravity is situated outside the tilting edge of the crawler travel gear, the machine then tilts over this tilting edge. Quick tilting-over is prevented by hydraulic presses which dampen the tilting motion and straighten the machine up again.

The travel gear of this machine has four crawlers, two of which are rigidly connected to the substructure, and the other two are connected by means of a balance beam with the third supporting point of the substructure being arranged in its centre. This balance beam supports the two cylinders contributing to the stability of the machine (Fig. 21).

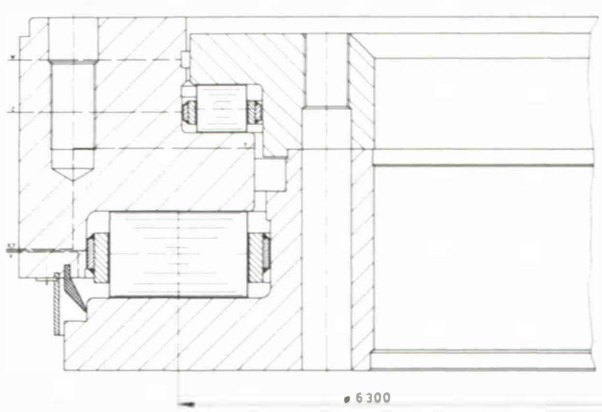


Fig. 20: Roller bearing for bucket wheel excavator in the oil sand open-cut.

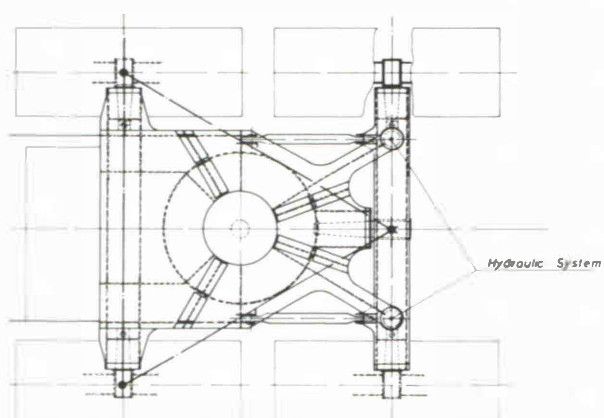


Fig. 21: Travel gear with 4 crawler chains and hydraulic tilting prevention system.

The lower support of the discharge conveyor which is subjected to considerable stress by horizontal forces on the one hand and vertical forces on the other, consists of a ball bearing whose design, in particular with reference to the material used, was newly developed. The surface of the race for the balls, consisting of high-class welding deposit, still has the elasticity required for such a running surface in spite of its hardness. This very expensive ball race is only used where conditions demand its application. On this machine, the restricted assembly space available for this ball bearing necessitated this special design (Fig. 22).

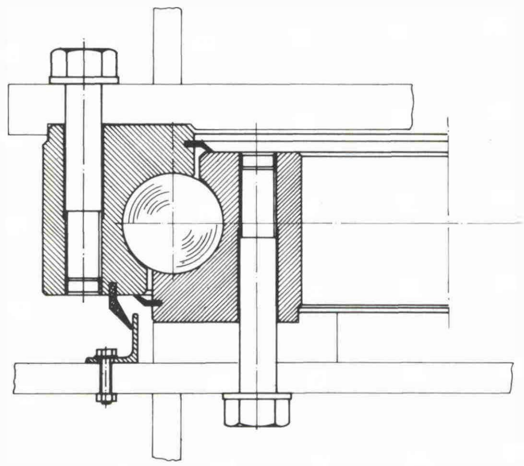


Fig. 22: Special design of a ball bearing.

Applications on considerably inclined grades require that a bucket wheel excavator is capable of standing or being moved even on inclinations of 1 : 6. As early as 1955, O&K built such a machine type for a brown coal mine in Italy. On this machine, the whole slewable superstructure can be levelled by means of an intermediate table fitted above the substructure.

Therefore, all parts of the superstructure are unaffected by the effects of inclinations of the track level. The intermediate table is rigidly supported in one point on the substructure, the other two supporting points can be adjusted in height by means of spindles. In this way, the inclination of the substructure can be equalized by means of the intermediate table, so that the slewable superstructure remains approximately level (Fig. 23).

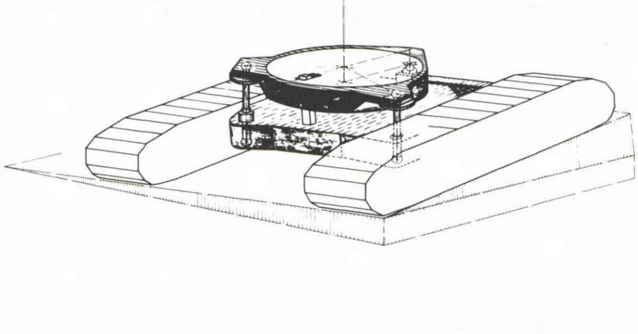


Fig. 23: Levelling equipment for the slewable superstructure.

This design, however, has the disadvantage that a certain overal height is required for the intermediate table and that, therefore, the pivoting point of the bucket wheel boom on the slewable frame must be arranged high up. This requires a long bucket wheel boom and great structural weight.

For this reason, new ways were found for a bigger machine in 1964. Levelling of the whole slewable superstructure was abandoned, only the conveyor belts were kept level. With this design, the whole machine adapted itself to the respective inclination of the grade, and this was appropriately taken into consideration when designing the different components. As, however, conveyors no longer run concentrically in case of too great an inclination transverse to their running direction, the horizontal position of the belts transverse to their running direction on this machine must be ensured even with big inclinations of the track level.

Control of the belt levelling devices is effected in such a way that the transfer conditions at the transfer points are not affected. The discharge belt is, for instance, supported in a cradle and when being levelled by a hydraulic cylinder moves in such a way that the material discharged from the belt in the bucket wheel boom always drops centrally on to the discharge belt (Fig. 24).

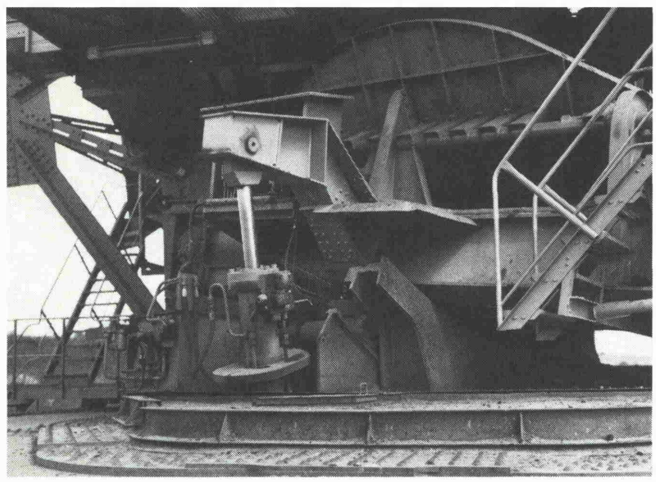


Fig. 24: Levelling equipment for the discharge belt.

At the beginning of the seventies — building on experience gained with hydraulically operated shovels — O&K developed the first all-hydraulically operated bucket wheel excavator with a nominal bucket capacity of 0.4 m^3, an output of 500 m^3 (bank) to 1,000 m^3 (bank), depending on the material, and a drive power of the three drive motors of the bucket wheel of 160 kW. The first machine was put into operation in the chalk pit Hemmoor in Northern Germany in 1972. It is being used successfully for stripping the overburden above the chalk. Since it was first put into operation, this machine has met all expectations (Fig. 25). On the basis of this unit, several machines with lower or higher capacities were built. The power can either be supplied via cable from outside or by built-in diesel engines. Several machines of both versions have been operating for years.

In 1967, Compagnie Française d'Entreprise placed a contract for the supply of a bucket wheel excavator system for construction of the Chasma-Jehlum Canal in Pakistan.

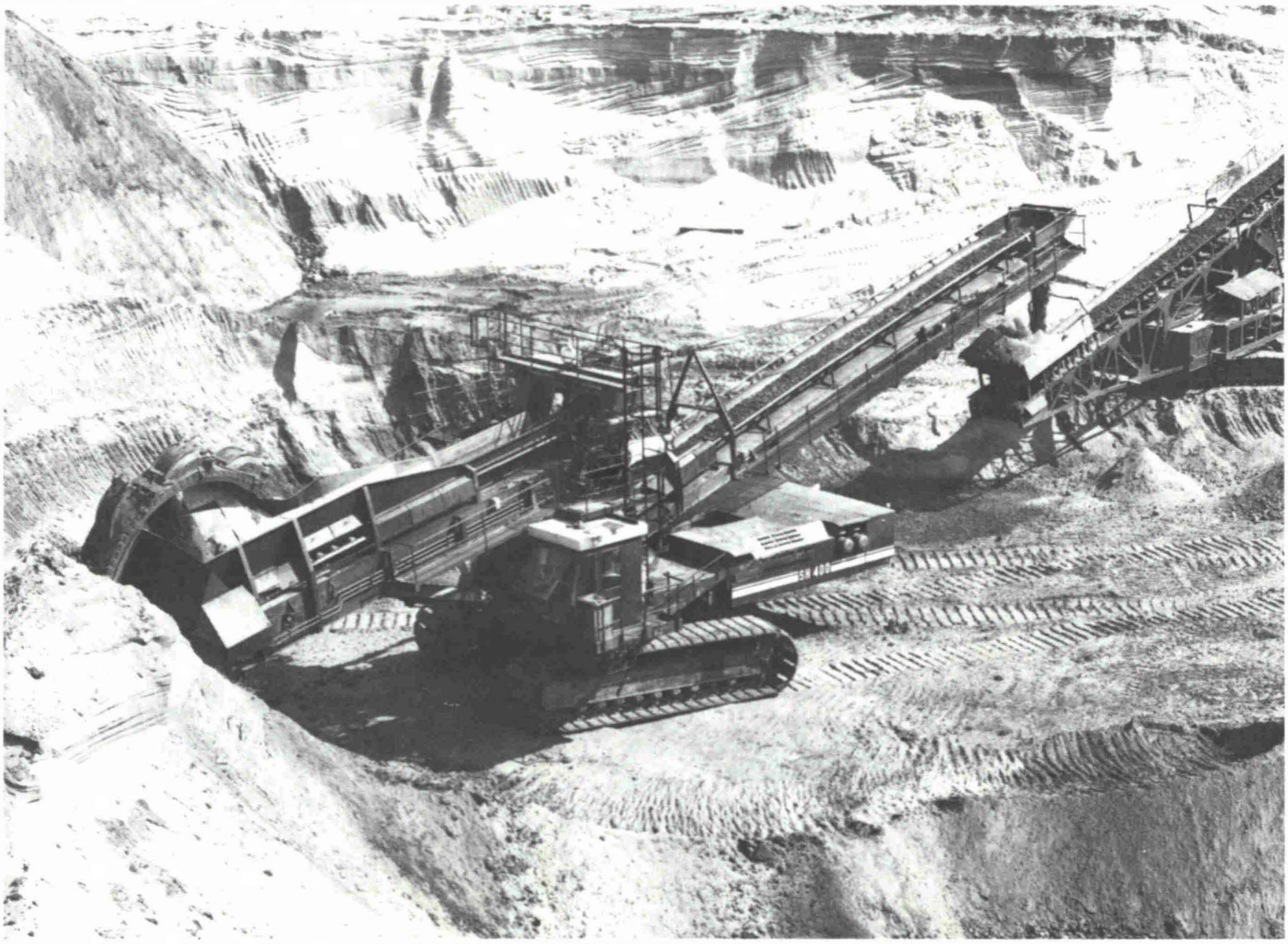


Fig. 25: Bucket wheel excavator in the chalk pit Hemmoor

Bucket wheel diameter	6.3 m
Bucket wheel drive	160 kW
Output per hour	1,800 m³ (loose)
Service mass	184 t
Motor power installed	495 kW

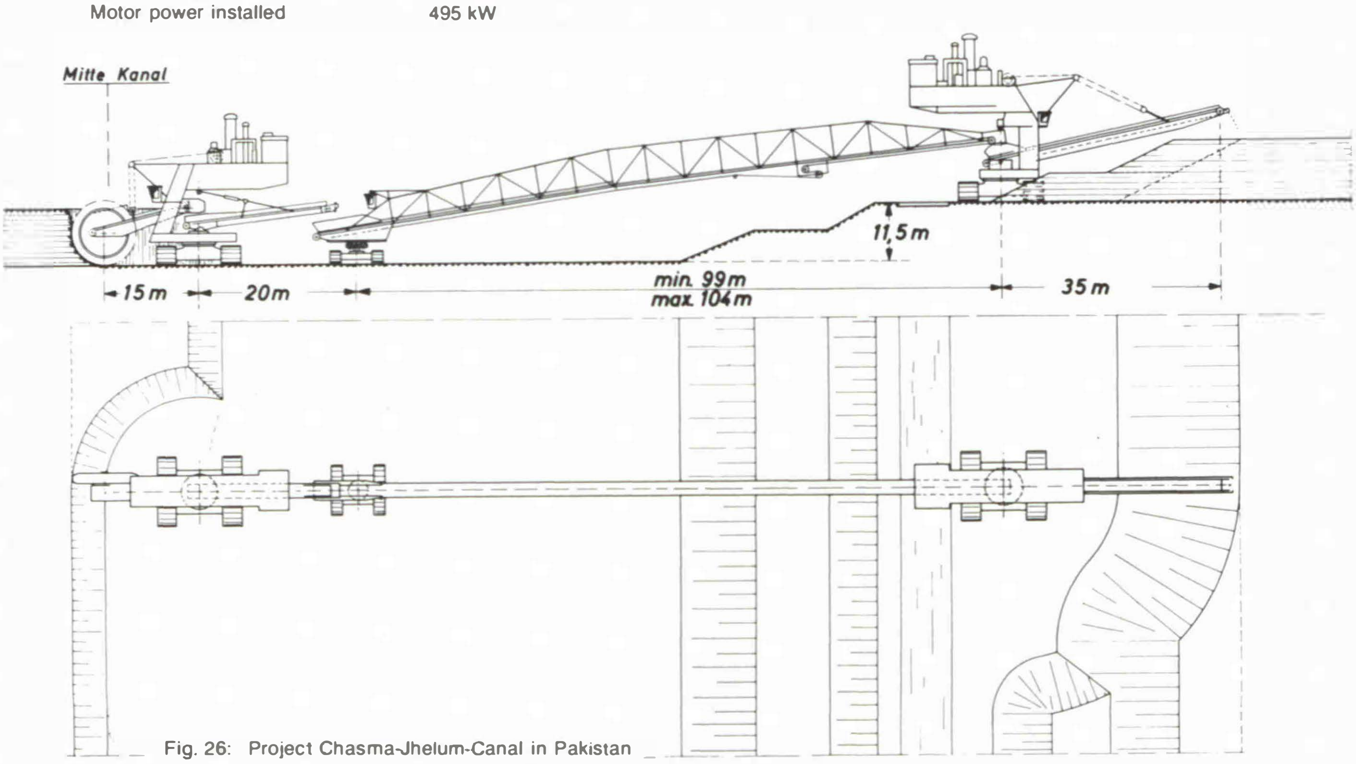


Fig. 26: Project Chasma-Jhelum-Canal in Pakistan

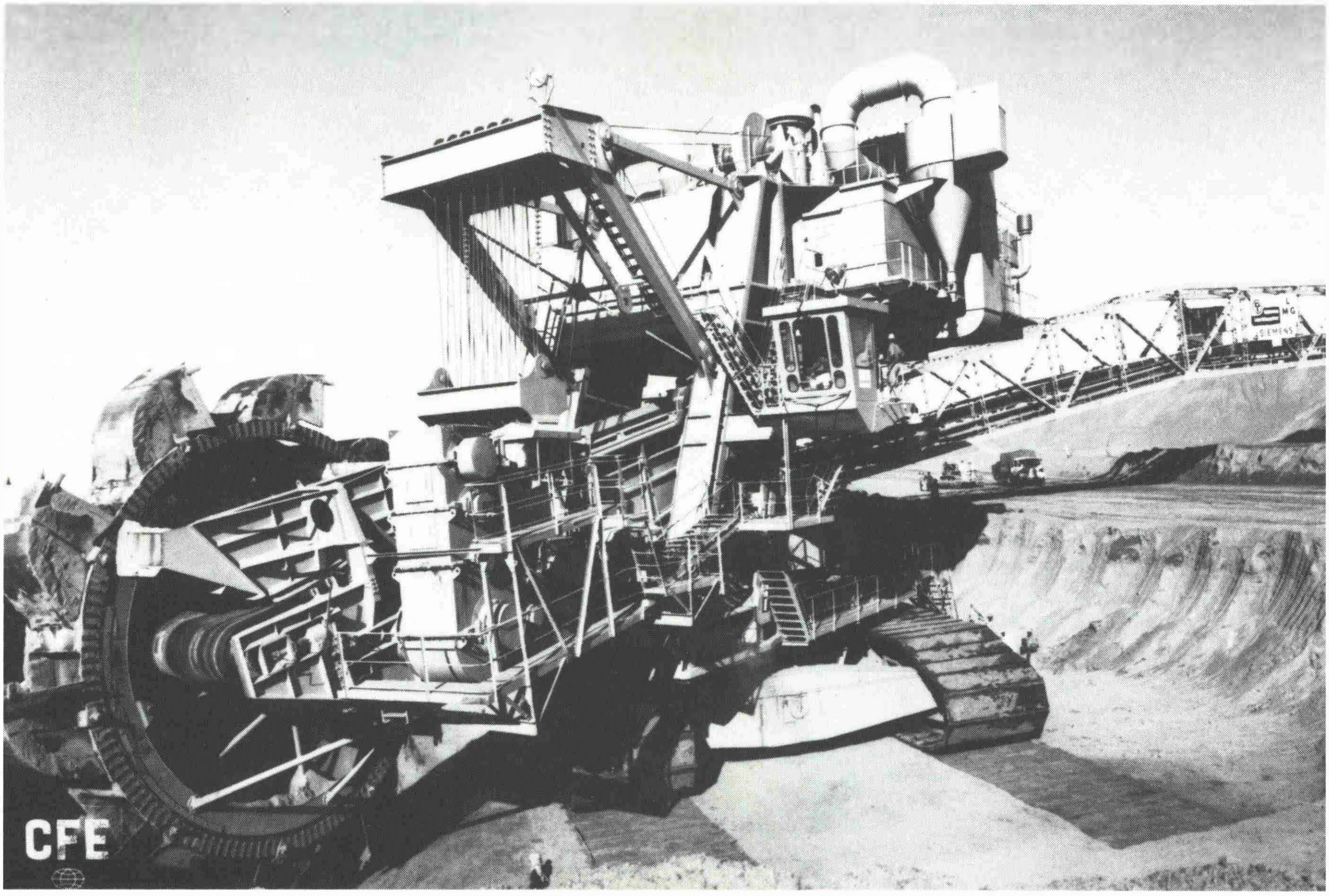


Fig. 27: Bucket wheel excavator during construction of the Chasma-Jhelum Canal, Pakistan

Bucket wheel diameter	10 m
Bucket wheel drive	2 × 360 kW
Output per hour	8,880 m^3 (loose)
Service mass	952 t
Motor power installed	1,900 kW

Total system: excavator + conveyor bridge + spreader

Service mass	2,110 t
Motor power installed	3,900 kW

This system was ready for operation in fourteen months, the components were made in Germany, shipped to the site, and erection was carried out there. Operation of the machine was started in mid-1968 (Fig. 26).

The whole system, a bucket wheel excavator followed by conveyor bridge and spreader, was designed for an average output of 3,750 m^3 (bank) an hour, but had to be designed for a maximum output of 8,800 m^3 (loose) per hour. Along its operating distance, the machine had to travel through zones of soils with little bearing capacity. The average bearing pressure was, therefore, not permitted to exceed 130 kPa (13 N cm^{-2}). The power is generated on the system itself by four diesel engines. Two engines each are accommodated on the excavator and on the spreader. As the machine had to operate under very unfavourable climatic conditions at ambient temperatures of up to 55 °C and sometimes during heavy sandstorms, the air required for the diesel engines as well as for the generators had to be thoroughly cleaned.

That was not only done by filters but additionally by precleaning by means of mechanical equipment. All these devices are attached to the housing in which the diesel and generator equipment is accommodated (Fig. 27).

With this bucket wheel excavator system, the company commissioned with building the Canal succeeded in moving masses of 46×10^6 m^3 (bank) along a Canal length of 97 km by the end of 1970 and, thus, completed the canal six months earlier than planned. During this time, the system has mined 4,800 m^3 (bank) maximum per hour and produced a monthly peak output of 2.3×10^6 m^3 (bank). The total travel distance of the system for digging the canal was 1,250 km. After completing the work on the Chasma-Jehlum Canal, the system was bought by another French Company for use in the construction of the Jonglei-Canal in the Sudan.

For operation in the Sudan which placed higher demands on the bucket wheel excavator as regards the material to be mined, several modifications were carried out in connection with the bucket wheel. After these modifications were carried out, the system is working at the moment in the construction of 380 km Jonglei-Canal also under very adverse climatic conditions. The system has an average output of 70,000 m^3 (bank) per day.

Acknowledgements

The author would like to thank the management of O&K Orenstein&Koppel, Werk Lübeck, Federal Republic of Germany, for permission to publish this article and for making available illustrations and photographs. The author is also indebted to the many mining companies which use the bucket wheel excavators described in this paper.

This paper is an edited version of a paper first published in "Braunkohle" E I/82.