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Methods for Exploratory Drilling of Deposits of Mineral Commodities –

Part III

Exploratory Drilling Methods for Extraction of Cuttings

Basics of the Pneumatic Down-the-hole-hammer technique

In principle the continuous extraction of almost undisturbed drill cores, provides samples of highest quality, which grant a high amount of information about the drilled mountain. The advantages with regard to the validity and reliability of the samples is contrasted by a comparatively high specific expenditure of time and costs for the core drilling process. In reviewing possible alternatives, there is a need to take into consideration the expected quality and quantity of the sample and the goal of the exploration. In case the assessment of the required quality of the samples reveals that drill samples are not mandatory to achieve the exploration target, exploration costs and time can significantly be reduced with drilling samples which can be obtained more efficiently. One of the most effective drilling techniques in hard rocks is the down-the-hole-hammer method.

This method is characterized by a rotary-percussive loosening process of the rocks. The loosening energy on the bedrock comprises of a static proportion of the pressure (approx. 10%) and a dynamic proportion from the impact energy (approx. 90%). The impact energy for demolition of rocks is applied immediately above the bottom of the bore hole by the drilling tool, which is a down-the-hole-hammer. Hereby the energy of the mud is converted into mechanical energy by a piston striking mechanism and is transferred via the bit into the mountain. The bit of the down-the-hole-hammer demolishes the rock over the entire cross-sectional area of the bore hole bottom and produces cuttings. During the loosening process, rock fragments sized a few millimeters up to approximately 20 mm are generated, depending on the geo-mechanical composition of the mountain and the incorporated loosening energy. In contrast to the core drilling method, in which a cylindrical rock is cut from the mountain, the hammer drilling is to be classified as solid drill method. The loosened rocks are continuously transported above ground with the mud as cuttings, in line with the loosening process. Apart from some special cases, down-the-hole-hammer systems are operated with compressed air as mud. The advantage of compressed air are in its almost unlimited availability, its easy production and disposal, as well as in its compressibility and the energy content entrained in the compressed medium.

Due to the almost unlimited availability and possibility of compacting atmospheric air with a compressor, transporting it with a corresponding volume flow in a closed piping system, and letting it escape after usage with little processing effort, no closed mud circulation is needed. Fresh air can continuously be taken in and led to the down-the-hole-hammer, in a clean condition. Therefore all components of the striking mechanism in the down-the-hole-hammer that are sensitive to dust and rock particles, are protected against excessive wear during operation. The striking mechanism consists of a piston, a cylinder liner, in which the piston is lifted and lowered axially in linear motion, as well as in overflow channels with an automatic driving mechanism. This mechanism serves to fill and empty the two air chambers in order to lift and lower the piston. After passing through the striking mechanism the compressed air reaches the bore hole bottom through the outlet openings and cleans them from the loosened cuttings.

Composition of a conventional down-the-hole-hammer (exemplary)
red: Drill bit, blue: piston, grey: casing and cylinder tube [3].
The Conventional Down-the-hole-hammer Drilling Method

In the conventional down-the-hole-hammer drilling method, the compressed air reaches the down-the-hole-hammer through borehole drill pipes and flows above ground in the annular space between the drill pipes and the borehole wall (direct wash drilling method). Due to the low carrying capacity of the flushing-air, the rate of ascent should be at least 15m/s. In order to reach the flow rate, volume flows of 8-35 m³/h (in relation to atmospheric pressure) are needed, according to the drill diameter. The actual flow rate is determined by diameter ratios in the annulus, by the pressure conditions in relation to load and depth which lead to a compression, as well as by the mud loss.

The actual rate of ascent of cuttings mainly results from the flow rate, as well as from the size and density (relation of weight of matter to its volume; specific weight) of the individual cutting particles.

With the conventional down-the-hole-hammer drilling method, it is possible to efficiently sink flat boreholes up to a depth of approximately 150 m with a bore diameter of 90 mm up to approx. 254 mm in compact hard rocks. In these diameter-depth areas in stable, dry and compact hard rock, the down-the-hole-hammer drilling is superior to most drilling methods. If concessions are made to the optimum drill performance, the conventional down-the-hole-hammer method can also produce cuttings with a drill diameter of up to 750 mm (with special tools and clustering of several hammers up to approx. 1,800 mm) and final depths of over 250 m. The technically sophisticated system components guarantee a high reliability. In medium-hard and compact formations with little fractures and carst caves, a drilling progress of 30 m/h to 70 m/h is achievable. The performance and application of flushing-air offers optimum preconditions for its application as extraction drilling technique. Since the mid seventies the conventional down-the-hole-hammer drilling method has managed to establish itself as a standard method for the creation of explosive drilling holes with a diameter of over 90 mm, in hard rock open pit mining.

As this drilling technique has established itself in this spectrum of tasks and performs well in this regard, there are efforts to apply this drilling technique in the exploration of deposits.

High performance of the down-the-hole-hammer method is achieved through optimum configuration of system components with regard to:

- The characteristics of the rocks to be drilled through
- The intended borehole construction (depth, diameter)
- The adjustment of the individual system components

The technical system components are mainly as follows:

- The drill string, composed of down-the-hole-hammer and drill pipes
- The compressor, which provides flushing-air
- The drill equipment for lifting, lowering and rotation of the drill string

The consecutive observations are related to system components, which are suitable for the diameter range of 90 mm to 254 mm. The dimensioning of the down-the-hole-hammer drilling tool is mainly done according to the desired drill diameter, the rock to be drilled, as well as the existing operating pressure. As a principle the following statement can be made: the higher the permissible working pressure of the hammer is, the higher is its performance. With the development of the hammer technology and the currently available slot control, as opposed to the older versions with valve control, it was possible to increase the permissible operating pressure from approx. 12 bar to 24 bar. Hereby the minimum operating pressure lies between 8 to 10 bar. In case of a modified construction of the high performance hammers, operating pressures of up to approx. 34 bar are permissible. The advantage of the down-the-hole-hammer drilling technique in exploration of mineral raw material deposits, lies in its high drilling performance in hard rock mountains. It is for this reason that the capacity of the hammer should always be fully used and to the extent possible the hammer should be operated with the maximum operating pressure. Under an optimum operating pressure, down-the-hole-hammers can produce a frequency of 1,500 to 2,000 impacts per minute. The occurring pressure losses in the drill pipes and annulus through the static pressure of the production column, as well as a pressure loss in the cyclone should be taken into consideration while planning and designing compressor performance.

The dimensioning of the diameter of the down-the-hole-hammer is done according to the planned drill diameter. A professional dimensioning of the diameter of the drill bit and hammer will create the most optimal relation between the effective piston area of the hammer and the area in the borehole bottom , which is to be worked upon by the bit. Transport of cuttings in the annulus between hammer and bore hole wall is also considered. The size of the annulus
should allow for an unhindered transport of cuttings particles in the loosened size. However, an annulus which is too largely dimensioned, reduces the flow rate of the flushing-air and as such reduces its load capacity.

The almost completely percussive loosening process is done by the drill bit through the induction of impulses generated by the down-the-hole-hammer. The principal construction of the drill bit can be divided into an upper admission or leading collar and a work surface for loosening of rocks. The solid drill is connected to the down-the-hole-hammer with the leading collar. It enables the transfer from the torque and allows for a uni-axial degree of freedom for accomplishing impact energy. The work surface of the drill bit consists of a base body, which is equipped with a number of individual hard metal rods in a calculated profile. The hard metal rods fragment the material at the borehole bottom. Due to the circular motion of the drill string the work surface is moved, so that the hard metal rods hit unloosened rock with each impulse. Furthermore the working front includes mud channels, which conduct parts of the flushing-air to the bore hole bottom. They ensure immediate and complete cleaning of the borehole bottom from the loosened cuttings.

The drill bits are adapted to the characteristics of the rocks to be drilled by constructively designing the number, outstanding length and size of the hard metal rods, as well as the form of the bit front. Through designing these characteristics it is possible to specialize the bits to ensure a particularly high drilling progress, improved leading stability or higher service life. At this point, however, only three standard faces, the concave, convex and flat face, are explained (see fig. 2)

- The concave face is suitable for very hard formations with a compression strength of up to 300 MPa. Furthermore, due to its low susceptibility to wear, this face can cope with abrasive and disturbed formations. A further advantage is its high leading stability, which leads to a reduction in borehole deviations.
- The convex face is suitable for drilling through formations with low to medium hardness, e.g. argillite or limestone, with a compression strength of up to 180 MPa. This face is characterized by a very good cleaning of the borehole bottom, which supports a very high drilling progress.
- The flat face can be applied almost universally. It is suitable for loosening medium-hard to very hard formations with a compression strength of up to 300 MPa and moderately abrasive characteristics. The flat profile allows for a balanced relation between directional stability and drilling progress.
The generation of the flushing-air, which serves to bring up the percussive loosening energy and the transport of the cuttings, plays a key role in the down-the-hole-hammer drilling technique. On one hand, the generation of compressed air has high energetic costs (overall efficiency of approx. 6 to 8%), on the other hand, it guarantees an optimum drilling progress. An efficient drilling process requires an optimal adjustment of the compressor performance to the type of the applied down-the-hole-hammer, depending on the drill diameter, the calculated pressure losses in the compressor performance, as well as the planned final depth. Based on these factors, the pressure and volume flow to be produced by the compressor have to be determined. The input for the calculation of the pressure generated by the compressor is the working pressure of the down-the-hole-hammer. Furthermore, the pressure losses from the flow in the drill pipes, the lifting of the production column and the pressure requirements at the sampling equipment have to be added to this calculation. The required pressure and the flow losses increase with the depth of the drilling. The inflowing groundwater has a considerable influence on the required pressure in the flushing-air. In case it intrudes the borehole, it increases the density of the column to be lifted. The required flow rate refers to the volume intake by the compressor under atmospheric conditions. Fig. 3 depicts the minimum value for the volume intake by the compressor for the maximum working pressure of 24 bar, depending upon the drill diameter.

Due to the fact that the obtained samples from the down-the-hole-hammer drilling method is of low quality, this drilling method receives only conditional or regional acceptance as an exploratory drilling method. The low quality of the samples results from the loosening and extraction process, which has already been explained in this article. Approximate values for:

- the interfaces and formation boundaries
- the thickness conditions
- the ground water conditions

can directly be obtained from the drilling samples and from the careful observation of the drilling process. In a further analysis (e.g. through geochemistry) and appraisal, detailed information about

- The rocks of the drilled-through mountain
- The resources in the deposit body

Can be obtained. In addition to the low information content of the samples, the reliability and quality is impaired by the following factors:

- The physical and geometrical characteristics of the cuttings particles, particularly the size, the form and the density
- The distribution of various characteristics of cuttings in the transport stream
- The loading of the flushing-air with cuttings
- The composition of the borehole wall with regard to the caliber trueness, open interfaces and zones that are prone to caving material.
- The volume of the groundwater and the flow rate of the ground water which intrudes into the borehole

Fig. 3: Minimum air volume of conventional down-the-hole-hammers at an operating pressure of 24 bar, dependent on the drill diameter.
These disturbing influences basically increase with the length of the production length (borehole depth), the uncased hole production length in the mountain, as well as the size of the annulus. The different characteristics for cuttings lead to different ascending speeds of the individual particles. Small drilling particles with low density flow past bigger and heavier drilling particles. Thus, with increasing production length, the mingling of cuttings, which were loosened in various depths, increases. This is aggravated by the fact, that due to the unsteady conveying process, the depth, from which the material was actually loosened, can only be determined by approximation. In formations that can be drilled well and in which there is good drilling progress, the loading of the flushing-air increases. The high differences in density of cuttings versus the compressed air have a direct effect on the compressibility of the conveyor medium and thus on the flow characteristics. The pressure needed for conveying increases when ground water flows into the borehole, therefore the characteristics of the cuttings can change through reactions with water (agglutinate) and the characteristics of the annulus can also be impaired through agglutinative material.

Sample quality deteriorates over longer drilling sections, due to sedimentation of cuttings on the borehole wall, in scourings and at the drill pipes. After drying the sedimentary coatings are diluted and will return into the mud. Therefore the real depth of their origin cannot be determined. The low density of the flushing-air can result in further impairment of the sample quality. The borehole wall cannot be stabilized with the flushing-air. Loose rocks from already drilled formations can fall into the production unhindered, which also leads to a falsification of samples. Furthermore sample quality can be impaired through the loss of cuttings. Apart from in some special technologies, in conventional down-the-hole hammer drilling methods no protective casing is laid. It is for this reason that during the drilling of jointed and karstified sections of the mountain, flushing-air can flow into the cavities and push aside the existing filling of joints. The flushing-air that flows off contains the cuttings, so that losses in the sample amount occur. During the flowing off of the mud a distinction is made between partial and total losses. These can occur temporary, e.g. up to the filling of a cavity, or can occur long term in widely ramified joint structures. In such cases the extent of stabilization of these formation sections and the additional efforts to made needs to be determined.

The loosened cuttings which are conveyed above ground are lead in a closed system from the entrance of the borehole to a cyclone, in which the cuttings are separated from the flushing -air and sampled. The entire drilled material is not included in the sampling. Samples in the amount of approx. 5 to 15 kg are taken from the extracted rocks in defined depth intervals of approx. 90 to 160 cm, and are packed in special sampling cases for transfer to geo-chemical analysis.

The quality of the samples is incomplete and to some degree considerably disturbed and therefore both the quality and reliability are only of limited acceptability. Nevertheless it is possible to use this low-cost and powerful drilling method for obtaining adequately accurate information for a statement of trends regarding the resource contents, the interfaces and the conditions of thickness, under the following circumstances:

- Final depths of 30 to 100m
- Dry mountain conditions
- Stable borehole wall
- No or low interference zone

The Down-the-hole-hammer Drilling method with Inverse Mud System

The production system of the down-the-hole-hammer drilling method was modified and the down-the-hole-hammer system with inverse mud system (indirect direction of mud flow) was developed with the aim of giving the down-the-hole-hammer drilling method a broader suitability for the exploration of raw material deposits in hard rock mountains. This drilling method has been in operation since the mid-eighties and has established itself as a standard method for the exploration of mineral deposits, next to the core drilling technique.

The inverse mud system uses the inner drill string for mud and cuttings transport to the surface, while fresh mud is flowing to the bit through the annulus. The drilling samples which are transported in the ascending mud flow are protected by the drill pipes and therefore do not have any contact with the borehole wall and the drilled mountain, respectively. Furthermore the mud channel in the drill pipes offers advantageous streaming characteristics, due to the constant and geometrically favorable cross-sectional area of the mud flow, as well as the smooth-walled tubular casing. The production system, which is closed and favorable to stream ensures the extraction of disturbed drilling samples, which have a suitable depth-appropriate, complete and unaltered quality for a broad spectrum of exploration tasks. The significant improvements of the basic quality characteristics of drill samples, compared
to the conventional down-the-hole-hammer drilling methods can be attributed to the following factors:

- The withstanding of caving material
- The reduction of entrance of ground water
- The reduction of losses of cuttings
- The reduction of mud losses

The key technology for the meaningful combination of the pneumatic down-the-hole-hammer drilling technique with the indirect direction of mud flow is double-walled drill pipes with bolted connections. Since the end fifties double walled drill pipes have been in operation for the exploration of soil formations under difficult circumstances as the so-called „Dual Wall Reverse Circulation Drilling“ method, which is also called the “Becker-Hammer-method“. The annulus between the outer and inner tube of the double-walled drill pipes offered an additional closed mud route. The advantages over all other piping systems, which entain an additional closed piping system to the lowest point of the borehole, (e.g. the flange pipe of the airlift drilling), are on one hand the complete integrity of the additional piping, on the other hand the support of the bolted connections. The bolted connections between the individual rods provide for connecting and loosening with justifiable time expense.

The dimensioning of the drill pipe parameters is mainly done through the mechanical resilience for torsion and tension, as well as by the biggest outer diameter, the diameter-influences area of the passed through annular gap between the inner and outer tube, as well as the streamed-through surface of the inner mud channel. The outer diameter is decisive for the flow surface, but is subject to the drilling diameter. With the dimensioning of a small annulus between the borehole wall and the outer shell of drill string favorable conditions are created for the size of the streamed-through areas in the piping and the stabilization of the borehole wall, though the grinding forces in the piping movement increase.

It is common to have a clearance of 8 to 15 mm in smaller drilling and piping diameters, and with increasing drilling/piping diameters a clearance of up to 110 mm. The stream surface, which is derived from the diameter of the inner mud channel, is decisive for the velocity of the ascending mud. The working volume flow is determined by the air consumption of the down-the-hole-hammer (manufacturer information), as well as the highest possible loading condition (ratio of the mass of loosened cuttings to the production), so that the rate of ascent of the mud can be calculated from the passed through area of the mud channel (without taking the compressibility into consideration). In order to have a good load of the compressed air flow, the rate of ascent of the mud should reach a flow rate of 20 m/s to 45 m/s. While coordinating the components for an optimum production system, the ratio of the drill bit surface (or the area of the borehole bottom) to the diameter of the inner tube should approximately be 2.3 to 2.7 :1. This geometrical ratio rises to approximately 6:1 for bigger drilling diameters.

Due to its construction, the double-walled down-the-hole-hammer drill pipes has a 20 to 60% higher specific mass than conventional down-the-hole hammer drill pipes, which has to be considered both in the handling of the drill pipe, as well as in the drilling control and the logistics of the entire drill string mass. As a basic principle, (partly) mechanized auxiliary attachments are needed for handling the set up and discarding of double-walled drill pipes. Double-walled drill pipes with the often used outer diameter of 4 ½” usually have a weight of over 90 kg at a standard length of 3 m. The following figure

![Fig. 4: Double-walled drill piping; the mechanical burden is taken up by the outer tube, the inner tube serves as a feed pipe [10].](image-url)
shows the expected specific mass of double-walled down-the-hole-hammer drill pipes (green area) and conventional down-the-hole-hammer drill pipes (red area) over the outer diameter of piping.

The loosening work can in principle be done either by conventional down-the-hole-hammers or by down-the-hole-hammers that are specially constructed for application with inverse mud system. The compatibility between the flushing-air, which in indirect mud direction is led through the double-walled drill pipes through the bottom of the borehole, and the conventional down-the-hole-hammer which is constructed for the direct mud direction, is established by an additional crossing in the drill string, the so-called cross Over Sub. The Cross Over Sub is positioned immediately above the down-the-hole-hammer and enables the mud flows to cross (see fig. 6). The pressured air which is supplied through the annular gap, is led through the central mud channel of the conventional down-the-hole-hammer. The mud exits through the mud openings of the drill bit, cleans the borehole bottom and ascends in the annulus between the down-the-hole-hammer and the borehole wall up to the Cross Over Sub, loaded with cuttings. The diameter of the Cross Over Sub is only slightly smaller than the drilling diameter, so that a flow barrier is created at this point in the annulus.

The flushing-air which is loaded with cuttings can get into the mud channel of the drill string through sidewise openings and ascend below ground. During operational use it is possible that impairments of sample quality - already known in conventional down-the-hole-hammer methods - can be caused in the mud flow from the borehole bottom to the Cross Over Sub. Furthermore, during drilling of friable formations, it is possible that scourings at the borehole wall are created, which can, together with the entry resistance at the Cross Over Sub, lead to a loss of mud flow and sample material in the upper annulus.

With down-the-hole-hammers that are specially constructed for the application with reverse mud flow it is possible to have an almost completely closed production route from the borehole bottom to the sampling. These are equipped with the so-called Center Sampling Technology, with which the loosened cuttings are immediately taken up through the opening in the drill bit, and lead to the inner mud passage of the drill piping. With Reverse Circulation Down-the-hole-hammers, it is possible to consequently convert reverse circulation mud flow.

The RC hammer is principally different from conventional down-the-hole-hammers in the construction of its hammer mechanism. The piston, as well as the flow- and control channel allow for a central mud channel through the hammer mechanism, the so-called sample tube, which enables the fluidic connection of the drill bit to the mud passage of the drill piping. The flushing-air which is led to the down-the-hole-hammer flows through the air chambers to the drive of the hammer mechanism and is led through mud channels along the collar of the drill bit, further on through mud channels in the bit to the borehole bottom or

Fig. 5: Specific drill string weights of conventional down-the-hole-hammer drill pipes and double-walled down-the-hole hammer drill pipes.
the lower part of the annulus, that is engaged with the bit stroke. The cleaning of the free punch and the borehole bottom is made possible through the division of the mud stream. At the upper annulus space, the open mud route is closed by a Chulk Collar.

The chulk collar creates an almost complete form fitting between both the outer tube and the cylinder tube, respectively, as well as the smooth borehole wall with correct caliber (see fig. 8). In a professional combination of the bit caliber and the diameter of the chulk collar, there is a gap of approx. 1.5 to 1.8 mm, so that only a negligible part of the flushing escapes into the upper annulus (less than

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**Fig. 6:** Schematic picture of application of a Cross Over Sub for the application of the conventional down-the-hole-hammer for the RC drill method.

**Fig. 7:** Exemplary depiction of a RC Down-the-hole-hammer [12].
10% in an optimum adjustment and without signs of wear).

The principal configuration of the RC down-the-hole-hammer drill bit is based on the configuration of conventional drill bits of down-the-hole-hammers. The already tested and proven constructive characteristics of conventional drill bits for loosening cuttings, e.g. the form, size and arrangement of the hard metal bolts, as well as the form of the working surface for suitable drill bits for the RC hammer, have mainly been kept. Constructive differences can be found in the design of the flushing channel. The mud jets are located in the outer annulus and the bigger inlet strainers are located on the inner annulus and in the center of the bit front, respectively.

Almost every manufacturer has his own hammer-bit-system. This is true for both the inlet and the drill collars in the hammer, as well as for the suitable configuration of the diameter between these tools components. In general, the highest specific loosening work can be achieved through configuration of the biggest possible diameter of the down-the-hole-hammer to the required diameter of the drill bit. In such a combination the maximum value is derived from the relation of the piston surface of the hammer to the loosening surface at the borehole bottom. With the choice of a bigger bit diameter at an identical down-the-hole-hammer the specific punch, in relation to the sole surface, is reduced. The advantages of combinations with bigger bit diameters lies in the wear behavior of the cylinder tube of the down-the-hole-hammer and in the low torque, which is due to the bigger annulus. The available RC down-the-hole-hammer systems that are offered especially for the exploration drilling technique are relatively narrow in the possibilities for combinations of the recommended drill bit diameters. Thus the difference between the biggest and the smallest bit diameter of a hammer often is less than 45 mm (1 ¾”).

In exploration of mineral raw material deposits, drill diameters with RC-down-the-hole-hammer drilling systems in the areas of 112 mm (4 ½”) to 165 mm (6 ½”) are prevailing. In this caliber range on one hand it is possible to use the geometric conditions for realizing an efficient extraction and loosening technique, on the other hand the cuttings volume can be reduced to a minimum, with respect to the purpose of drilling.

In analogy to the conventional down-the-hole-hammers, the operation parameters of the RC-down-the-hole-hammer technique are characterized by the pneumatic performance characteristics. The punch of the hammer is generated by the effective piston surface, as well as by the operating pressure of the mud. The loosening operation in the down-the-hole-hammer method is almost exclusively generated from its punch. The aim of each impulse in the process of rock demolition is a demolition under the borehole bottom, which is as profound as possible. The mechanical properties that have to be overcome by the loosening tools increase with depth in rough and compact hard rock mountains, due to the increasing pressure jacket, which impacts the area under the borehole bottom. among others, the suitability of a down-the-hole-hammer technique that is suitable for increasing depths is subject to the permissible operating
pressure. Apart from the operating pressure, the actual performance of down-the-hole-hammers is influenced by the constructive design of hammer mechanism, drill bit and mud routes. Depending on the manufacturer and model range, down-the-hole-hammers of approx. 24 to almost 50 bar are available. In selecting a suitable RC down-the-hole-hammer, it is important to find an optimal benefit-effort ratio between the required loosening performance of the drill tool and the energetic costs for generation of pressurized air.

The required flow rate for the respective operating pressure of RC down-the-hole-hammers is in principle slightly less than for conventional down-the-hole-hammers. In the following figure the air consumption per operating pressure is shown for three model series. These are optimally suited for a drill diameter of 5 ¼” to 5 ¾” and operate with various operation parameters.

The mechanical operation parameters, i.e. pressure, rotational speed and torque are comparable to the ones of the conventional down-the-hole-hammer technique and are relatively unexacting to the drill tool technique. In principle the down-the-hole-hammer drill bits are constructed for a percussive rock loosening process and do not have cutting rock loosening characteristics.

In an optimum adjustment of rotation, the arrangement of the hard metal rods is dislocated in a way, that with each percussive impulse they hit and demolish upcoming material. The adjustment of the rotational speed is a function of the optimum circumferential speed and subject to the bit diameter, the actual percussion frequency, as well as the dimension of the crater generated by each hard metal rod. With optimum impact frequency and depending on the drill diameter from 112 mm (4 ½”) to 165 mm (6 ½”), it is recommended to use 60 and 20 rpm.

The drill pressure counteracts the backlash force of the hammer and the axial vibrations in the drill string. The drill pressure does not have any influence on the rock loosening process. Therefore the pressure on the hammer should basically be kept as low as possible. Based on the cross-section area, a minimum pressure of 3 kg/cm2 and a maximum value of 8 kg/cm2 should be targeted. It is for this reason that drill pipes that freely stand on the hammer exceed the pressure load of most down-the-hole-hammers after a few meters, so that the drill string of the drill tool needs to be backpulled.

Fig. 9: Operating characteristics of various RC-down-the-hole-hammers in a representative selection of different performance classes.
In deposit explorations with the RC-down-the-hole-hammer method, apart from a few exceptions, only drill tools with top drive that are established on a mobile basis platform and are operated diesel-hydraulically are applied. The hook load during regular drilling, as well as exceptional pull back in extraordinary conditions are basic parameters for the dimensioning and choice of drilling rigs. The regular pull backs which should be handled by the drilling tool results from the mass of the drill string, the top drive, as well as the grinding force of the drill string at the borehole wall. The maximum drill string weight results from the specific mass of the drill piping, the planned final depth, as well as the mass of the drill tool.

In estimating the needed hook load, the tractive force from the free and perpendicular hanging drill pipes should be increased with a loading factor of 1.7 to 2.2 for grinding forces and losses. Due to the fact that the annulus is not flown through by mud, as well as due to the dimensioning, the RC drill string is principally subject to a higher friction, particularly in not straight-axle gradient borehole sections and fissured formations. Under the preconditions of exploration drilling techniques a safe estimation of the truly occurring grinding forces is only insufficiently possible. Therefore, often oversized drilling rigs are chosen to ensure operational safety. In the following figure the retraction force to be calculated is depicted for an often applied drill string configuration, which is suitable for a drill diameter of 5 ½” (140 mm) in a 4 ½” drill string and a 5” RC-down-the-hole-hammer.

The drill rigs that are designed for the RC-down-the-hole-hammer method are typically equipped with a top drive to generate rotation. The top drive should generate a constantly turning momentum of approx 1500 to 12000 Nm and a rotational speed range of approx. 15 rpm to 100 rpm, which to the extent possible should be continuously adjusted. Furthermore the top drive is the technical connection between the non-rotating elements of the feeder or pulling equipment, as well as the fixed part of the mud system with the rotating drill string. The mixture of flushing-air and cuttings, which ascends in the inner drill string, reaches a fixed piping system through a centrally integrated swivel in the top drive. The piping system connects the drill string to a cyclone for the separation of the cuttings from the mud. The mud feeding into the annular gap of the double walled drill piping is done through a second swivel, which is installed between the top drive and the drill string. In the technical basic equipment of the RC-down-the-hole-hammer drilling it is essential to have compressors for the supply of the flushing-air, plus cyclones for the separation of the cuttings samples from the mud flow.

The optimum selection and dimensioning of compressors is decisive for the economic and technical success of the down-the-hole-hammer drilling technique. The best coordination between energy costs, drilling progress and tool/bit service life can be achieved with the correct
parameterization of fed pressure and flow rate. In order to do so, it is necessary to carefully plan with the following criteria:

- **Operation pressure of the RC-down-the-hole-hammer**
- **Required operation flow rate of the RC-down-the-hole-hammer**
- **Required production flow rate for generation of a sufficient rate of ascent**
- **Adjustment of the pressure losses that are due to formation, drill string and depth**

The operation characteristics of RC-down-the-hole-hammers were discussed in previous sections and reflected in fig. 9. From there it can be concluded that the maximum permissible operation pressure is up to 48 bar. In standard applications, RC-down-the-hole-hammers have a usual operation pressure of up to 35 bar. They need a operational flow rate of approx. 30 m³/min, based on a temperature of 20°C and an atmospheric pressure of 1 bar. While calculating the pressure to be supplied, it is necessary to calculate the actual differential pressure at the down-the-hole-hammer. Therefore the following have to be added to the operating pressure:

- **The dynamic pressure losses of the flushing-air**
- **The dynamic pressure losses of the ascending flushing-air**
- **The static pressure of the production column**
- **The operation pressure of the cyclone**

The dynamic pressure losses result from the function of the pressure-dependent flow rate and the length of the piping system. The dynamic pressure losses at the components can be well calculated and considered. The calculation of the static pressure losses, however, is more complicated. They are dependant on the composition of the mixture in the production column. In particular the influx of ground water can considerably increase the pressure potential of the production column. Due to the complex function and input parameters, which need to be accurately defined, the exact calculation of pressure losses will not be discussed here.

On the basis of I. Speer [16] it is possible to use approximate values with a simple estimation. According to that estimation, the following approximate values are used for the application of double-walled drill pipings with a diameter of 4”:

- **Dynamic pressure losses of the supplied mud, approximately 0,17 bar / 10 m**
- **Dynamic pressure losses of the ascending mud, approx. 0,23 bar / 10 m**
- **Static pressure losses in the production column after reaching ground water level with approx. 0,69 bar / 10 mWs**
- **Constant pressure losses at the flushing head, cyclone, etc. with approx. 1,86 bar**

In fig. 12, the approximate values are presented as a function of the borehole depth in the dry borehole, as well as the exemplary assumption of a ground water influx from a drill depth of 300 m.

The parameters of the compressor have to be derived from needs-based dimensioning of pressure and flow rate. In order to do so, the upper and lower threshold value of the pressure to be released have to be determined. The lower threshold value is determined from the maximum value of the pressure losses and the lowest operation pressure of the down-the-hole-hammer, the upper threshold value is determined from the minimum value of the pressure losses, and the highest permissible operation pressure of the down-the-hole-hammer. Due to the pressure losses related to depth and ground water, it is better to use compressors with various power levels or continuously adjustable aggregates with increasing borehole depth. The technically and economically meaningful performance spectrum that can be generated with compressors is limited due to the disposal of a flow rate of approx. 30 to 35 m³/min under a pressure of 30 to 35 bar. In this performance category usually screw compressors with a power of approx. 400 to 540 KW are used. In case the operation power of a primary compressor is not sufficient, a booster compressor can be used. The booster compressor is supplied with the pressurized air of the primary compressor and increases its pressure level. Due to the enormous volume compression it might be necessary to connect several primary compressors for the supply for a booster compressor. For RC-down-the-hole-hammer drills, booster compressors with a moderate compression strength of approx. 70 to 150 bar and with a discharge of a relatively high flow rate of 70 or 40 m³/min are suitable (in relation to 1 bar, 20°C).

The application of booster compressors in down-the-hole drill methods can lead to higher target depths, although the energetic costs for the generation of pressurized air considerable increases. In handling highly pressurized flushing-air, it is particularly important to consider safety
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and retraction force or hook load of the drilling rig, it is possible to achieve final depths of drill holes of up to 500 m (see fig. 14). It is possible to achieve target horizons of 1,000 m with the application of particularly strong compressors and drilling rigs. The RC-down-the-hole-hammer method can achieve a drilling progress of 20 to 40 m.

Conclusion of Drilling Exploration Techniques

In drilling exploration of mineral deposits in hard rocks both the (diamond) core drilling, as well as the down-the-hole-hammer drilling with reverse circulation mud flow dominate. The advantages and disadvantages of both methods can be found in the achievable drill performance, the technology used and the quality of samples. The relatively young down-the-hole-hammer drilling method with reverse mud circulation has pushed aside the classical core drilling method in global exploration activities (mineral raw material). However, since different criteria of suitability of both methods open up complementary areas of application with a competing intersection, even in future core drilling will not completely be driven out by the RC-down-the-hole-hammer drill method. With regard to the extraction of qualitatively high samples currently the core drilling method is superior to the RC-down-the-hole-hammer drilling technique, the exploration of deeper target horizons, as well as for applications in areas that are precautions for handling, combining and maintaining of the tool components.

Extraction of the drilling samplings is firstly done through separation from the mud stream and secondly through reducing them to a manageable material amount and packaging it in sampling storage vessels. The cuttings are separated from the mud stream with the help of cyclones. With progressing drill depth of 1 to 2 m the samples are collected in regular intervals and are filled into bags. However, the amount of loosened rocks of approx. 25 to 55 kg/drift meter (drill diameter of 4 ½” to 6 ½”) is in excess of the needed sampling material. After separation from the mud stream the incoming cuttings are reduced to approx. 1/7 to 1/12 by a splitter, so that a representative cuttings sample of approx. 2 to 5 kg per drilling meter is taken.

In order to do geo-chemical analysis, this amount is again reduced by extraction. Since the appraisal and storage of the entire drilled material exceeds economically acceptable costs, this reduced method produces representative samples from a relatively big outcrop window, which is particularly beneficial for the appraisal of deposits with irregular material distribution.

The final depth which is to be achieved with the RC-down-the-hole-hammer drilling method is mainly limited by the mass of the drill string or by the required compressor strength and retraction force or hook load of the drilling rig, it is possible to achieve final depths of drill holes of up to 500 m (see fig. 14). It is possible to achieve target horizons of 1,000 m with the application of particularly strong compressors and drilling rigs. The RC-down-the-hole-hammer method can achieve a drilling progress of 20 to 40 m.
Fig. 12: System combination of compressor and booster for an operation pressure of up to 69 bar; installed drive power of approx. 500 kW [7].

Fig. 13: Planning scheme for the dimensioning, as well as for coordination of drill string, compressor and drill tool.
difficult to reach or for impassable fields. The RC-down-the-hole-hammer drilling methods can achieve economic benefits due to a high drilling progress. Furthermore it is better possible to determine the material content on the basis of samples of cuttings in highly irregularly distributed deposits due to the bigger outcrop window (drill diameter).

In case of the RC-down-the-hole-hammer drilling method, its application in difficult to reach drilling locations is opposed by the drill string and equipment masses that need to be mobilized. In the drilling planning a higher drilling progress has to be contrasted with the partly considerable costs of high drill rigs for logistics, energy supply and drill sites, as well for as its recultivation.

The range of application of the conventional down-the-hole-hammer drilling technique has only very little overlap and hardly competes with the application area of the RC-down-the-hole-hammer drill technique and the core drilling technique. However, due to the low quality of samples, the conventional down-the-hole-hammer drilling technique is denied a higher importance as an exploration drilling method.

Due to varying operating situations and changing geological conditions, the suitable drilling technique for the exploration of mineral raw material cannot be limited to the mentioned standard drilling methods. In particular exploration tasks, technologies that have been designed for other drilling tasks are suitable. In this report they will not be taken into consideration, as they are applied as special technologies in the exploration of mineral raw material deposits.

Bibliography


Univ.-Prof. Dr.-Ing. habil. Hossein H. Tudeshki studied from 1977 to 1980 at the Mining College of Shahrud (Iran); following several years of work in the mining industry, he completed his mining study at the RWTH Aachen in 1989. Since 1992 he was Chief Engineer at the Institute for Surface Mining (Bergbaugunde III) of the RWTH Aachen, mainly active in the field of open cast mining and drilling technique. He did his doctor degree in 1993 and qualified as a university lecture in 1997. In 1996 the Venia Legendi was awarded to him by the RWTH Aachen for the field “Rock and Earth Open Pit Mining”. In November 2001 he was appointed as Professor for Surface Mining and International Mining at Clausthal University of Technology. He already has over 25 years of experience in the field of project planning and cost-benefit analysis within the frame of various mining projects. The international tasks rendered by him mount up to more than 380 international raw material-related projects.

Dipl.-Ing. Heiko Hertel, born 1975, graduated in the years 1995 to 1998 trained as a well constructor. The activities of the well constructor he held until 2001. Immediately following the same year he began the study of Geotechniques, Mining and Petroleum Engineering at Clausthal University of Technology. He completed his studies successfully in 2007 and is engaged in silk as a research associate at the Institute for Surface Mining and International Mining at Clausthal University of Technology.
Vermeer has transcribed its long-standing experience in the area of rock mills into its new surface mill. The T1255 is characterized by protected technology, intelligent design, excellent production and system stability. Meanwhile the Terrain Leveler can process an area of up to 3.7 m width and 61 cm depth in one single run.

The machine has been designed to ablate all kinds of rocks, gypsum, coal and other material (e.g. concrete). This is done using a big, hydrostatically steered milling drum, which ablates the rock in a more efficient way and with a higher cutting depth.

**The result:**
More coarse material with a low proportion of fine fraction.
Research approach and procedure for the estimation of empirical parameters for straight drilling of blastholes

Drilling and blasting is the most frequently used method of production in hard rock open-pit mining processes. Borehole deviations are a major source of danger concerning the safety and the environment. Moreover, they have adverse effects on production and cost efficiency. Therefore, this article introduces a concept for detection and evaluation of the causes for borehole deviations. The results will be applied in a concept to optimise the drilling process with respect to drilling accuracy and precision. The objective is to be able to drill blastholes without or at least only minimal deviation in any given geological environment.

Motivation and research objectives

The present situation

In open-pit mines for stone production drilling and blasting are the most frequently used production processes. Ground motion and fly stone are major emissions which occur during the blasting process in the stone industry. While former adversely affects the nearby surrounding communities in densely populated areas, the latter endangers machines and workforce on the production plant. Deviations of blastholes boost up the danger of fly stone and ground motion. Conflicts and lawsuits with neighbours will negatively influence public acceptance as well as the production process and economic viability.

Dense population and spatial approach of residential areas to the production plant leads to growing importance of blasting emissions and consciousness of its dangers. The potential of danger due to fly stone and conflicts caused by emissions should therefore be minimised by making use of the technological and planning potential. Precise drilling and drill-hole measurement support a better planning of the appropriate blasting energy. Thereby, the risk of fly stone and ground motion can be reduced to a minimum.

Using the blasting energy more efficiently has positive side effects on the quality of the rock pile and it helps optimising the energy balance and reducing blasting fume. A homogeneous rock pile quality due to a more homogeneous distribution of grain size has positive effects on downstream production processes as loading, transportation, and processing. Less boulders and ribs need to be reworked. Mucking and secondary blasting is significantly reduced by better blasting. The scale of crushers can be lower and less energy will be needed for more homogeneous muck. Lower capital and operational cost are incurred due to lower power consumption and small scale crushers.

Because of blasthole deviation the wall will be irregular geometrically designed. This in turn makes the calculation of the blasting energy more difficult and will lead to higher operational costs. If blasthole deviation could be avoided, subsequent errors as boulders and irregular wall design could be avoided as well, capital and operational costs are reduced.

Overall, precise and accurate drilling is a key task which can help to improve consecutive operational processes. However, the reasons for drill hole deviations are not well understood. Therefore, further research on precision in percussive drilling technique is inevitable.

The objective of straight hole drilling depends on several interdependent parameters. Literature suggests the following parameters as most relevant [15], [16], [17]:

- geological, petrophysical, and tectonic parameters,
- machine technological parameters,
- production, and mine design parameters,
- workforce skill, and experience as well as production planning,
- other parameters like hole inclination and azimuth.

Capturing, quantifying and assessing the factors as well as their interdependency on borehole accuracy and precision enables to develop a drilling concept for the stone quarrying industry. The project consists of field studies as well as theoretical research.
**Problem description**

The most important precondition for safe blasting and low emissions is precise drilling. Precision drilling is a very challenging process in the quarrying industry.

Possible mistakes which lead to deviations of blastholes can be avoided easily. Deviations may be caused by the choice of a wrong drilling angle, azimuth, and/or pre-drilling faults outside the hole. Nevertheless, deviations may also be caused by drill string behaviour inside the hole. Drilling through anisotropic, jointed and inhomogeneous rock with a certain inclination causes forces at the shaft end which may lead to deviations in hole trajectory [19].

Figure 1 shows possible directions of the borehole deviation. It may be that the drill string deviates to the burden (Fig. 1, no 1). This leads to an increase in fly stone and dust emission. Two adjacent blastholes may also deviate in azimuth that local overcharging of blastholes occurs because the distance between the hole-end is narrower than initially planned (Fig. 1, no 3). Increased risk of fly stone and dust emission is inevitable in this case, too. Larger than proposed distance to the next shothole induces local undercharging and thereby increased ground motion because the burden cannot be blasted sufficiently and the shock wave will be reflected. The same effect has a hole deviation backwards into the rock (Fig. 1, no 5).

The shockwave is directed backwards into the rock mass, the wall cannot be blasted. This leads to increased ground motion [4], [18].

Another consequence can be an inadequate wall design with ribs and rock toes at the bottom.

It is obvious that by enhancing precision in drilling the risk of fly stone and ground motion can be reduced. Moreover, consecutive processes like loading, transportation and processing are supported positively by a more homogeneous grain size of the rock pile.

In order to charge the deviated shot holes properly a precise measurement of the wall and the hole trajectory is essential. Despite the enormous time consuming and financial effort of bore hole deviations no satisfying solution exist up to date for precise drilling. Therefore, the objective should be to develop a concept for precision in percussive drilling in the quarrying industry.

**State of the art in drilling and hole measurement of the quarrying industry**

**State of the art drilling**

For drilling holes with a maximum length of 30 m in the quarrying industry, predominantly percussive drilling is applied.

Fig. 1: Possible drilling errors [6].
Top-hammer and down-the-hole-hammer (dth-hammer) differ in the place where the shock wave energy is generated. For top-hammers the piston is placed at the drill rig outside the hole. Whereas dth-hammer generate the impact energy just above the drill bit inside the hole [19].

Losses in impact energy at the rock-bit contact zone are detrimental to the penetration rate. This is especially true for top-hammers. Impact energy loss occurs due to friction in between the rod and the hole wall, and at the rod couplings. With growing hole depth the penetration rate decreases faster for top-hammers than for other techniques due to the before mentioned losses in impact energy. Moreover, the rod is exposed to higher stress and wear.

Dth-hammers are appropriate for difficult drilling conditions and larger depth. Light weight and low-cost construction offer more application possibilities (vertical and horizontal drilling). In general it is assumed that straight drilling is easier with dth-hammers compared to top-hammers even for long holes. Nevertheless, the performance of dth-hammers compared to top-hammers is assumed to be lower, especially for short holes [10].

The COPROD top-hammer system of ATLAS COPCO is an alternative to the common drilling techniques [1]. It combines the precision of the dth-hammers with the performance of top-hammers [1]. The rod consists of a combination of impact rods and drill rods. Whereas the impact rods transmit only the impact-power, the drill rod is responsible for rotation speed, thrust, and flushing. The floating impact rod does not have any thread couplings. The shockwaves of the piston can be transmitted frictionless. Therefore, the drill rods have a high durability and lifetime. Although the COPROD system seems to be well fitted for drilling straight holes it may possibly not be available for this research.

The optical hand clinometer helps to determine the azimuth and the inclination of each hole. A torch or a mirror is let down the hole at a rope. If the source of light is not recognisable any more a deviation lager than the diameter is evident. With the clinometer one can measure the inclination of the hole. The depth can be measured easily with the rope. If it is impossible to determine the hole trajectory to the bottom other methods should be applied [3], [13], [16].

A system to determine the position of the bottom of the blasthole relative to the burden is called “DIADEME” [14]. The system consists of a fully mobile sender and a receiver with a wired sensor and a handheld display unit. The wired sensor is let down to the bottom of the hole. The sender is moved in a steady way along the wall and thereby sends out electromagnetic signals. The receiver in the bottom of the hole transforms the signal into the distance between sender and receiver. The relative position, the thickness of the burden as well as the distance to adjacent holes can be calculated and graphically displayed by a computer. Nevertheless, there are some disadvantages of this system: the time consuming process of measuring each hole and possible inaccuracies due to magnetic influence [3], [13], [16].

The COPROD top-hammer system of ATLAS COPCO is an alternative to the common drilling techniques [1]. The rod consists of a combination of impact rods and drill rods. Whereas the impact rods transmit only the impact-power, the drill rod is responsible for rotation speed, thrust, and flushing. The floating impact rod does not have any thread couplings. The shockwaves of the piston can be transmitted frictionless. Therefore, the drill rods have a high durability and lifetime. Although the COPROD system seems to be well fitted for drilling straight holes it may possibly not be available for this research.

The most reliable and meaningful method to measure borehole parameters up to date is “BORETRAK” delivered by MDL. The sensor which is let down at a wire measures the inclination and the azimuth directly. The borehole length depth can be derived from the cable length. The parameters hole length, inclination and azimuth are measured in short intervals. A handheld device stores the information which can later on be analysed on a computer. The software “HoleDev.6” analyses and compares the measured data with the planned parameters and delivers a graphical output for every hole as well as for the whole set. Combined with a laser based measurement of the wall the masterburden can be determined exactly. Measurement accuracy is independent to magnetic influences or water inflows [7], [16].

Penpendicular measurement, circumferentor and mining compass, clinometer, or tachymeter-theodolit have been used a long time for wall face measurement. The work with these instruments has to be done just in front of the wall which can be dangerous and the results sometimes lack of accuracy.

Therefore, the blasting company “Westspreng” introduced a laser based wall measurement method which uses the “MDL-Quarryman” Software [14]. The vertical and horizontal angles can be determined as well as the distance to the wall up to 500 m. The measured data is transmitted to
a computer. The software “Quarryman” analyses the data and delivers a 3D model of the wall [7].

The company “Breithaupt” developed a special laser system called “LAPRO II” to determine the surface of profiles and walls in quarries [2]. The corresponding interactive software can depict walls and calculate the blasthole charge. Traditional systems calculate the wall profile in general based on the floor level and the ridge. The passive distance laser measurement allows determining the whole wall profile in between the ridge and the bottom level which has a high relevance for safety reasons.

State of the art direction control during the drilling process

Globally no device exists which can control the straightness of a blasthole during the drilling process. Also, no device has been developed until now which is able to avoid deviations of blastholes while drilling with reliability as far as the authors are informed.

Conclusions from the state of the art

It can be concluded that with state of the art drill rigs a blasthole deviation cannot be avoided with reliability. Only if geological, rock mechanical, production related, and organisational parameters are within optimal range a sufficient drilling accuracy can be ensured. If conditions are not optimal, deviations of blasthole are highly possible. Inhomogeneities, discontinuities like layers, joints, and tectonic faults are given, natural but not optimal drilling conditions one has to deal with. Based on observed deviations in optimal ground conditions, parameters should be developed which help to control hole trajectory. This is assumed to be a reasonable solution in order to deal with the describe problem.

Measurement technologies can help to identify blasthole deviations and to correct the dimension of the applied explosive energy. Nevertheless, these technologies cannot solve the major problem of the ex-ante deviation. Measurement systems can solely help in detecting deviations after drilling and in correcting blasting system. This in turn leads to a high financial and time consuming effort which should be avoided. Moreover, measurement takes place after the whole series of holes has been drilled. Errors appearing in the first hole therefore cannot be avoided anymore for the adjacent holes. The systematic deviation in general affects every hole of a series. Appropriate reaction of the workforce on errors is not possible.

In the way of this research the “Pulsar Blasthole Probe Mk3” is used to measure the inclination and the azimuth of the boreholes (see Figure 2). The measured values are recorded with the “TDS Recon X” and analysed with the software “Quarrypocket”. Later on, the data will be transmitted to a pc, processed, and analysed with the software “HoleDev.6”. A possible graphical output can be seen in Figure 3.

Despite the fact of blasthole deviation being the main reason for daily problems in quarries like fly stone, vibration immisions in the neighbourhood, still there does not exist a satisfying and reasonable solution to the problem.

Redevelopment of the RDi vs. development of a new index

The RDi (Rock Mass Drilling Index) has been developed to determine the drillability of rocks [5]. The index value helps estimating the expected penetration rate. The penetration rate is of vital economic and organisational interest for calculating and planning the drill work. The drilling time and the cost of drilling can be derived from the penetration rate. However, the determination of the penetration rate is only of secondary interest for this research. The objective is to develop a concept for straight drilling of blastholes. A redevelopment of the RDi does not seem to make sense at first sight but due to the similar input parameters the RDi could be revisited for the purpose of this project.

Technically the RDi is a rating system to determine the expected penetration rate. The drillability of rocks in the RDi depends on physical parameters (texture and grain size), parameters of rock strength (uniaxial compressive strength, Mohs Hardness), and structural parameters of rock mass (joints spacing, dipping, aperture & filling) [5]. Depending on the specific characteristics the rock mass is evaluated and rated in a certain classification scheme. The higher the determined rating of the rock mass the better will be its expected drillability. The span of the index ranges from 7 for poor drilling conditions to 100 for optimal conditions. Table 1 summarises the rating system of the index [5].

The RDi and the target value of this research have in common that they depend partly on the same parameters. But for determination of the deviation, discontinuities like tectonic faults and layers are also of high relevance.
Since the RDi does not include machine parameters like thrust, rotation speed, flushing and impact rate, does it make sense to extend the scope of the RDi on borehole accuracy? The result of a concept for straight hole drilling should be to derive a rating from the interdependent variables for the geology and the machine parameters. Whereas the geological parameters (rock strength, structure, texture and grain size) are given and fix, the machine parameters (rig type, hole depth, hole diameter, inclination, thrust, rotation speed, flushing) can be chosen in dependence of the given parameters. The objective should be to be able to forecast the expected borehole deviation from a given set of geological factors and to choose the right machine parameters in order to minimise the expected deviation.

The RDi can be redeveloped for the purpose of straight hole drilling because it has the same (geological) basis. Rock mass parameters are also relevant for blasthole deviation. The applied weights have to be redetermined. Interdependencies which influence the deviation may have a completely different character than the ones for the estimating the penetration rate. Drillability of a given rock mass may decrease the finer the grain and the denser the texture (see Table 1). The opposite may be true for straight hole drilling. Precision in drilling may increase the finer the grain size and the denser the texture. It should be possible to rank the influence of certain parameters on drilling accuracy. The general structure of the index does not need to be changed.

There are some requirements a concept has to fulfil. The character of a model is described by these requirements. Hoseinie et al mention four rules which have been considered for the development of the RDi:

(a) the number of parameters should be small,
(b) equivalent parameters should be avoided,
(c) parameters should be considered within certain groups, and
(d) the rock mass classification should be applicable in the field” [5].

The quality of a model depends on its optimal degree of abstraction. The more input parameters are considered the more complex (in dimension) will be the determination of the optimal parameters for the choice of e.g. the machine, rotation speed, thrust, and flushing. The derived values should be easily applicable in practice. Therefore, only the most important parameters should be considered. The concept has to be transferable for the use of...
different machine types and should be applicable for the most rock types. The optimal degree of abstraction will be a trade-off in between generality and speciality in conditions and technique.

The input scale depends partly on the kind of information the model should deliver. Following propositions are possible:

- exact forecast of \( x, y, z \) – coordinates for every drilled meter,
- exact forecast of deviation in \( x, y \) – coordinates for every drilled meter,
- probable forecast of deviation direction, and
- probability of a deviation (without direction).

\[\text{Table 1:} \]

\begin{tabular}{|c|c|c|c|c|c|}
\hline
Texture & Porous & Fragmental & Granitoid & Porphyric & Dense \\
\hline
Grain Size & - - & > 5 mm & 2-5 mm & 0,05-1 & 0,05-1 mm \\
Rating & 15 & 10 & 7 & 4 & 1 \\
Mohs hardness & 1-3 & 3-4,5 & 4,5-6 & 6-7 & >7 \\
Description & Very soft – soft & Comparatively soft & Comparatively hard & Hard & Very hard \\
Rating & 18 & 13 & 9 & 4 & 1 \\
UCS [MPa] & 1-25 & 25-50 & 50-100 & 100-200 & >200 \\
Description & Very low strength & Low strength & Average strength & High strength & Very high strength \\
Rating & 22 & 16 & 11 & 6 & 2 \\
Joints spacing (a) & >2 m & 1-2 m & 0,5-1 m & 0,15-0,5 m & 0-0,15 m \\
Rating & 18 & 13 & 9 & 5 & 1 \\
Joint aperture & -filling (b) & Closed joint 0-2 mm & > 20 mm & 12 – 20 mm & 9 – 12 mm & 2 – 9 mm \\
(b) & & & & & \\
Rating & 15 & 10 & 7 & 4 & 1 \\
Angle between joint and borehole axis & 70° - 90° & 55° - 70° & 35° - 55° & 20° - 35° & 0° - 20° \\
Rating & 12 & 8 & 6 & 3 & 1 \\
\hline
\end{tabular}

For investigation of parameters as to the joints system, in case of more than one set of joints, specification of dominant joint set are classified. In case of the joints set with the same importance, for each set of joint one RDi is obtained and the mean of RDi rates is the standard of judgement. For marginal values, the rate related to the lower class is appropriated.

(a) The rock masses which have rule-abiding cleavage and sheets, because of the drilling easiness, rate of 12 is assumed for spacing.

(b) For the joints filled with soil and very fine powders, the rate of seven is assumed for the fillers.
The given information differs in scale levels. Whereas the first two points deliver a metric scale information the third and fourth point are ordinal scale information. The scale level of the generated information depends heavily on the scale of the data input. If the input data is only nominal or ordinal the output can hardly be metric. Less parametric methods can be applied if the scale level is not metric. Nevertheless, this will lead to a loss of information. Therefore, if possible, metric information should be gathered.

Figure 5 depicts a possible structure of the index which has to be developed. The general structure is similar to the RDi. Nevertheless, this index pays more attention to the structural parameters of the rock mass. Apart from joints layers and faults are considered as well. However, the presented structure can only predict a probability of a possible deviation as it ranks the geological and mechanical conditions with respect to hole straightness. The right hand side of the proposed index structure gives recommendations about the mechanical options which should be applied in order to drill a straight hole with respect to the fix geological parameters.

In order to forecast and control the direction and the magnitude of the deviation detailed information about joints and rock layers are needed. Especially jointing may differ a lot from hole to hole. Therefore, a forecast of deviation due to jointing seems hardly possible. However, in practice it seems neither appropriate nor applicable for the drilling staff in terms of time and know-how needed to calculate the possible deviation magnitude and direction. Nevertheless, if the research results suggest that estimating hole trajectory is possible and applicable in the field it should be concerned.

Deviations of blastholes are not always as easy to recognize as shown in Figure 6. Though the deviations are obvious, a certain tendency cannot be derived from the simple view of the wall. Therefore, the holes have to be analysed with the introduced instruments. A statistical research design will be needed to detect certain, repeating tendencies.

Research procedure and statistical design

Before a new approach for straight hole drilling can be developed, the major reasons for blasthole deviation have to be unveiled with certainty. Only if the reasons for deviation are known without doubt, recommendation for the correction of the drilling process and the used drilling tools make sense. In the following a research procedure and the experimental design will be introduced. Sampling and data evaluation are an important part of the research.

In order to determine the reasons for not straight drilled holes test drills will be conducted. The samples consist of every relevant data concerning the geology, rock mechanics, machine data, pit design, and hole geometry. The collected data will have different scale levels. As far it is possible metric scaled data should be collected because the most transformations are allowed for metric values. Nevertheless, a lot of important data is only categorical or nominal scaled (e.g. tophammer or down-the-hole-hammer, drill bits, etc.).
Fig. 5: Indexstructure

Fig. 6: Borehole deviations in sedimentary rock, rotary drilling. Deviations are not always as obvious as in this example.
Other data can at least be ranked (degree of jointing, hardness on Mohs scale).

Recording machine parameters from the drill rig poses a severe problem. Only a few drill rigs (like the Atlas Copco Smartrig) can record thrust, rotation speed, penetration rate, etc. If recording is not possible only the employed (not the real) rotation speed and the employed thrust can indicate the applied real parameters at the drill bit-rock contact zone. In practice drillers vary speed and thrust relying on their experience and subjective sense of the penetration rate and danger of stalling. The lower the observed penetration, the higher will be the applied rotation speed and thrust. Hole deviation (or straightness) seems to be out of control. However, detailed information about machine parameters is inevitable for the purpose of research.

The only solution to this dilemma is to record the drill time per rod section and to calculate the penetration rate thereof. For the applied rotation speed and thrust one has to rely on the drillers statements.

In the first step open pits should be considered for sampling which differ in genesis of rocks (sedimentary, metamorphic, magmatic) but have similar drill tools. In practice it has proven hardly possible to select mines with comparable drill tools. The objective of at least comparable machines should nonetheless be pursued. The emphasis should be on the difference in between hole diameter and above all hammer technique (tophammer vs. dth-hammer). The objective is to find out which geological or rock mechanical properties tend to support hole straightness when machine parameters are at least comparable. The deposits are divided by their geological genesis into sedimentary, magmatic (intrusive and extrusive), and metamorphic deposits. Up to now sampling took place in the following geological formations:

- **Sedimentary:** shell limestone and massive (riff) limestone;
- **Metamorphic:** gabbro;
- **Magmatic:** andesite, rhyolite, basalt.

For the magmatic rocks most frequently a tophammer is used with similar diameters of 91 or 92 mm, semiballistic or spherical bits. In softer rock conditions like limestone quarries dth-hammer with larger diameters (115 mm) and ballistic bits are more common. Often external contractors are in charge of drilling. As mentioned before the comparability of drill tool technique is very important in order to exclude other causes than geological parameters for the blasthole deviation.

In every quarry at least 30 holes should be drilled and measured with the cabled “Boretrak” sensor. The number of samples should account for at least 30 for statistical reasons of significance. The variance of the sample should be approximately the same like the unknown variance of the normally distributed variable “blasthole deviation” on a high level of significance (above 90%).

Joints, layers and tectonic faults are mapped in advance and if possible after blasting. Samples of nearby and representative rocks will be analysed concerning their mechanical and physical (texture, grain size) properties. In some cases the companies will already have information about these rock material properties.

The next step will be to analyse drill holes in quarries with comparable geological genesis but different drill tool technology. The emphasis lies in the difference in between dth-hammer and tophammer technology. It is widely assumed that dth-hammers are more precise than tophammers which should be tested for significance.

Moreover, the tests should deliver a statistically significant correlation of the hole deviation and the corresponding factors (geological and technical parameters). From the average blasthole deviation with similar or at least comparable drilling technology one can derive the geological reasons (joints, dip of layers, etc.) for the deviation. Since the average deviation due to geological factors is known from the first sample, deviations outside the 90% confidence interval (lower or higher) of the average deviation may result from the different choice of technology.

Parameters for the choice of the drill tool are “semi variable”. They can only be varied and chosen before the drilling process starts whereas the drilling parameters like thrust and rotation speed are fully variable during the process within the limitations of the technology. A choice has to be made in between tophammer and dth-hammer. Bit design and rods offer another “semi variable” choice.

Figure 7 depicts exemplary a histogram of not representative, absolute borehole deviation in a quarry. It is obvious that the deviation (two dimensional in xy-direction) varies around the average of 0.8 m. The hole depth was 20 m. From the sample of 63 holes the variance and standard deviation was calculated. From the given distribution the assumption of normal distribution of the variable “blasthole deviation” cannot be falsified with...
certainty. The plot shows a tendency of the blastholes to deviate in inclination. The majority of the holes deviated backwards and to the right hand side (see Figure 8).

For the purpose of this research, deviations in drill angle (y-axis) and azimuth (x-axis) are of major interest (Figure 8). A deviation in depth (z-axis) is in general a result of deviations in x and y direction. The hole length can relatively easy surveyed by control the used rod length. Therefore, the absolute deviations in xy-direction are the target values of this research.

From the first two steps in the research program the most significant reasons for borehole deviations (or straightness) can be estimated. These insights should be applied in a concept for straight hole drilling in dependence of a given geology. A significant reduction of the average deviation should be testified as a result. This verification of the research results should take place in the same quarries as the test before. The developed concept for straight hole drilling should be applicable in every environment.

Besides the absolute deviation of blastholes the tendencies of hole trajectory is of interest. If a set of holes tends to deviate in the same direction common, mostly geological, phenomena is the reason for the observed deviation. Dipping of layers and joints is widely held responsible for those facts. However, changing angles, faults, and non-regular joints even within one blasthole series make it hardly possible to test, repeat, and validate similar environmental conditions. That is why the major challenge is to record blasthole and drilling data in dependence to hole length and to derive certain regularities. Technically, up to date, there is no device available for this research. The Smartrig technology of Atlas Copco offers a tool “measure while drilling” which may be fitted for those tasks. However, this device is not commonly used until now in the German stone quarry industry.

Data analysis

For the statistic data processing Excel is sufficient in most cases. For more pronounced statistical and graphical tools the use of statistic software (Statistica, SPSS, etc.) will be appropriate.
Various statistical methods will support the development of the drilling model. Before a statement can be made about a quantifiable relation of the parameters the absolute deviation should be analysed with respect to linear or non-linear dependencies. The correlation will be tested graphically as well as formally. For this purpose the absolute deviations of the boreholes in equal depths will be compared with the technical and geological parameters. The different scale levels have to be addressed properly.

Testing the correlation on significance makes sure that the results are not random. If this hypothesis can be rejected the linearity has to be tested. In advance a threshold should be determined in order to define linearity. A correlation coefficient (e.g. \( r \geq 0.5 \)) may be appropriate for the assumption of linearity. In a third step strength and direction of the correlation will be determined. Graphically one can assess the correlation by plotting metric values. However, if a linear interdependency cannot be revealed, a logarithmical, square or exponential may exist which can be detected by plotting a trend, as well.

When type and strength of correlation have been determined and can be approved theoretically, then a regression analysis is viable. The parameters determined by the OLS-method (ordinary least squares) should be tested on significance with the so called “f-test” and “t-test”.

The regression analysis estimates the absolute borehole deviation in dependency to the named parameters (technical, geological). Multi-collinearities may exist which should be avoided. E.g. the rotation speed is proportional to the impact frequency, or the Mohs hardness and/or uniaxial compressive strength may be direct proportional to porosity, grain size and form, texture, etc. [5].

The regression analysis helps in estimating the absolute deviation of holes with certainty under given geological and technological conditions.
Perspective and project schedule

In contrast to earlier approaches to the topic of borehole deviations the major objective of this work is not to determine exact physical and theoretical causes for the deviation (as in [8], [9], [11], [12]). Moreover, the assumed causes for imprecise drilling should be analysed quantitatively and statistically in order to derive a certain drilling pattern and to verify the theoretical assumptions statistically. The verified correlations in between geology, technology and the observed deviations will be quantified in order to deliver an empirical basis for precision drilling conditions. If possible, a positive side effect should be the estimation of parameters to adjust the drill process.

Possibly the theoretical assumption about causes of borehole deviations cannot be testified. Maybe completely unsystematic or random correlations will be unveiled, which cannot be estimated with regular statistical methods. This would either mean to falsify the theoretical assumptions or to resample data.

The general time frame for the first sampling period will take six months until the end of June 2010. Stand-by time in drilling and blasting due to bad weather conditions or operational revision processes have adverse effects on the schedule. Furthermore, unavailability of the respective drilling technology poses some difficulties for comparative studies. Most commonly it will not be possible to compare dth- and tophammer technology within one single quarry. The choice of quarries is thereby limited to the availability of drilling technology and geological genesis. Nevertheless, it should be possible to sample enough data for a multi-dimensional comparative study.

Bibliography

Thyssen Schachtbau has been involved in raise-boring projects in Switzerland for some seven years now. The company’s entry into this sector began in 2002 with the sinking of Sedrun II shaft for the Gotthard base tunnel. After Sedrun I had been completed using conventional techniques it was decided that Sedrun II shaft should be sunk by a shaft boring machine. This operation required a pilot hole to be drilled to provide a route through which the boring debris could be cleared away under gravity. The pilot drilling was carried out by an HG 330 raise-boring machine and the operation proved so successful for everyone involved that similar contracts were subsequently awarded. Three of the most recent of these projects are described in more detail below.

Developing the ‘Rüti’ quarry

The Rüti quarry development is located near Rotzloch quarry in the canton of Nidwalden and as at Rotzloch the new Rüti facility will be mining siliceous limestone. The stone is blasted in-situ and passed through a pre-crusher unit that reduces it in size to a maximum edge length of 350 mm. The material is then tipped into a vertical shaft for intermediate storage. The vertical shaft is filled to the top so that the material is not degraded by the impact. The shaft terminates in an ‘installation chamber’ where the stone is automatically diverted on to a belt conveyor that carries it through the Rüti tunnel, across the Rotzloch gorge and down the short Rotzloch tunnel before arriving at the new transfer station in the current Rotzloch quarry. A second belt conveyor then transports the product to the ballast works, where it is further processed into crushed stone and chippings.

The Shaftsinking and Drilling division was contacted about undertaking the vertical shaft project and was subsequently commissioned to carry out the work. The shaft was 130 m in depth by 3.0 m in diameter and was to be sunk using the raise-boring method.
Working sequence

After the tunnel undercut had been completed and the ‘dirt box’ chamber constructed, along with its concrete lining, the Wirth HG 250 raise-boring machine set to work.

The machine was set-up above ground on a pre-prepared drilling baseplate.

Drilling accuracy was a critical factor – the pilot hole had to come out ‘dead centre’ in the chamber roof. In order to meet this tough requirement Thyssen Schachtbau GmbH opted to use a rotary-vertical drilling system (RVDS).

Because of the length of the steering tool a vertical section some 6 m in length first had to be drilled out using a stabilised drill set before the RVDS could start work.

With the RVDS fitted into the drill string the pilot hole was promptly drilled downwards to the 12¼” (311 mm) diameter needed for the subsequent raise-boring phase.

After breakthrough the pilot drill bit was removed and the raise-boring head set-up in the chamber. The widening operation then commenced with the drill string and its reaming head drilling upwards to take the hole out to its final diameter of 3.00 m.

After breaking through to the surface the raise-boring machine was removed from the hole and the reaming head dismantled.

An excellent working relationship was maintained with the client company Gasser Felstechnik AG for the entire duration of the contract. This enabled the project to progress swiftly and a drilling advance of 20 m a day was achieved during the hole widening phase. All work was completed within schedule.

The location of the drilling site some 630 m above sea-level, along with the existing infrastructure and very narrow mountain roads, posed a particular challenge for transport and supply operations and for the assembly and dismantling of the drilling machine.

Local support was always on hand to help solve any difficulties encountered, including mud loss during the drilling operation. When this problem arose the local farmers sprang to our assistance by arriving with their water-wagons, while the fire brigade helped out by supplying a pump. Where else could we have obtained so quickly the water that we desperately needed for drilling, 630 m up a remote hillside at the foot of the Alps.

But of course the marvellous view and the nearby Lake Vierwaldstätter helped make up for the tough demands imposed by this most unusual of drilling sites.
Construction work on the CHF 31 million Schattenhalb 3 hydroelectric station began on 18.06.2008 and is expected to take two and a half years to complete. The contract to undertake the excavation work and build the penstock was awarded to the Schattenhalb consortium, comprising project partners Gasser Felstechnik AG, Frutiger AG and Montagen AG. The project also requires a 280 m inclined shaft to be raise-bored at an angle of 37° from the vertical, to give a height difference of about 218 m. The contract for this raise-borehole operation was awarded to the Swiss branch of Thyssen Schachtbau GmbH, who assigned as subcontractor the Swiss branch of the Italian-based company Edilmac.

The pilot drilling commenced on 10.03.2009 and was completed by 23.03.2009. The local rock was mostly stable and exhibited a high uniaxial compressive strength of between 120 and 200 MPa with a slightly inclined stratification. Given the proposed position of the new inclined shaft the local rock beds were not expected to generate a high overburden pressure. The drilling equipment comprised a Robbins 73 machine from Atlas Copco.

The 283 m-long pilot hole, which was to have a 37° deviation from the vertical, was first drilled with a TCI roller cone bit to a diameter of 12¼". The drill cuttings were flushed away using up to 1,200 l/min of clean water at a pressure of about 5 bar. A discharge channel was created on the bedplate in front of the drilling machine and the drilling mud with the drill cuttings was directed into the first of three settling tanks.

The drilling stack comprised the aforementioned roller cone bit, the roller stabiliser, the main stabilisers and drill rods 11¼" and 10" in diameter.

When planning the raise-boring operation the Schattenhalb penstock consortium decided for economic reasons not to use directional drilling technology. The work in the access drift leading to the bottom of the shaft was halted about 40 m before the planned drilling target point so that...
conventional drilling and firing could be used for the final few pulls in order to adjust the course of the drift to the line of the pilot hole. The borehole alignment and the coordinates at the bottom of the hole were first surveyed specifically for this purpose.

The pilot hole was reamed out to its final diameter of 3.05 m by a Sandvik raise-boring head working upwards from the underground installation chamber at the end of the access drift. The operation to widen the inclined shaft required less drilling mud than the pilot hole and only about 30 l/min was needed for flushing the debris and keeping the drill tool clean. The material excavated by the raise-boring head was removed from the shaft bottom by wheel-loader.

In spite of the technical problems, which included the failure of a drill-rod joint after 142 m of hole, the raise-boring head arrived at the top of the shaft on 24.06.2009. The rock being drilled through to create the final shaft diameter of 3.05 m was found to be extremely stable, in line with the geological prognosis, and the completed raise-bore shaft presented an extremely clean rock profile with no overbreaks.

After completing the raise-bore shaft to a length of 258.50 m the boring head was anchored into place and secured and the Robbins 73 removed. The upper section of the shaft head was excavated using hydraulic rock hammer on a hydraulic excavator and the 12 t raise-boring head was lifted out of the shaft by mobile crane and loaded-up for transport off site.

In summing-up the success of the Schattenhalb 3 penstock shaft drilling operation, which was completed between 9 March and 29 June 2009, Thyssen Schachtbau GmbH would like to acknowledge the excellent support and cooperation provided by the client and subcontractors alike.

Looking ahead, the inclined shaft will subsequently be allocated a strata reinforcement category, according to the local geological situation, and will then be secured by rockbolts and shotcrete. This will be followed by the installation of a corrosion-proof DN 1000 compression steel pipe, an inspection ladderway and various cable ducts.
Raise-boring for the Taschinasbach hydroelectric station

When planning the pressure-compensating shaft, or surge chamber, for the Taschinas hydroelectric power station the client, Rätia Energie AG, chose the raise-boring method as the preferred option. In April 2009 the project consortium ‘GrischaTaschinas’ awarded Timdrilling the contract to undertake the raise-boring work.

The drilling site was about 1,000 m above sea-level on the slopes of the Pileisch disposal area north of the village of Seewis-Dorf in the Prättgau district. Access was via a steep, narrow road with a number of hairpin bends that posed real problems when transporting equipment up to the site.

The disposal area was to be used for storing the material from the underground excavations (pressure shafts, surge chamber and so on).

The hillside location and the composition of the overlying rock immediately presented a challenge for the preparation and setting-up of the drilling site. The top 9 m of overburden comprised Quaternary loose rock material interspersed with cohesive clay.

In order to stabilise the overburden zone a circular bored pile wall was constructed down to the solid rock. The inside of this pile ring was also reinforced by cementation.

The set-up area for the drilling machine comprised layers of compacted excavation material topped by a bedplate. This baseplate was specifically designed to be able to absorb both the tractive forces generated by the anchored raise-boring machine when drilling the pilot hole and the compressive forces produced during the main reaming operation. The concrete foundations were required not only to serve as an abutment for the drilling equipment but also to distribute the loading forces of the machine in such a way as to effectively prevent the latter from sinking in and tipping over.

Project execution

Zum Erstellen des WIn order to construct the surge chamber a 48.8 m-deep vertical hole first had to be precision-drilled through to the roof of the underground installation chamber. By referring to local geological data Timdrilling was able to undertake this operation without resorting to a directional drilling system. When drilling the 12¼”-diameter pilot hole the drill string was reinforced with five stabilisers each 1.5 m in length. The homogeneous cementation of the bored piles also helped keep the drill string on line for the first 9 m of drilling.

The drilling mud, which consisted of clean water without any additives, was pumped-circulated through a 30 m³-capacity settling tank.

Drilling site for the surge chamber north of Seewis-Dorf, foundations and bored pile positions for strata consolidation. (Foto: Member of TS Gruppe)

Installation of the HG 160/2 drilling machine. (Foto: Member of TS Gruppe)

Above: Rotary drilling head of the HG 160/2 with rod feeder.
Below: Breakthrough for the pilot hole, reaming head fitted. (Foto: Member of TS Gruppe)
The pilot bore was completed in 1.5 working days. The reaming head, a Sandvik CRH3 unit with a cutting diameter of 1.05 m, was then set up in the underground installation chamber and the hole was reamed out from bottom to top. This operation was also completed in 1.5 working days.

Looking back on the project it can now be said that the borehole was drilled with accuracy and precision, according to specifications, and to the complete satisfaction of the client. No unexpected geological conditions were encountered during drilling.

For the next phase of the project the client will be fitting the surge chamber with a DN 800 centred steel pipe, after which the annulus will be filled with a concrete suspension.

We should at this point like to express our thanks to the client for all the preparatory work and for providing back-up throughout the project.

Summary

The projects described above have helped enhance Thyssen Schachtbau’s reputation in the Alpine region as a highly efficient and reliable raise-boring contractor. Further contracts for mining and hydroelectric construction projects are currently at the tendering phase. Thyssen Schachtbau GmbH are always on hand when it comes to delivering high-quality construction work.

FOR MORE INFORMATION AND CONTACT:

Thyssen Schachtbau GmbH
Sandstraße 107-135
45473 Mülheim an der Ruhr | Germany
Tel.: +49 (0)208 - 30 02 0
Fax: +49 (0)208 - 30 02 3 95
eMail: info@ts-gruppe.com
Internet: www.thyssen-schachtbau.de

Authors:
Tilo Jautze & Joachim Gerbig

Drift entry leading to the installation chamber.
(Foto: Member of TS Gruppe)
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Slope failures in clay open pits of Rhineland-Palatinate

by Ansgar Wehinger
State Office for Geology and Mining Rhineland-Palatinate | Mainz | Germany

In the clay mining district of the Westerwald exists the highest number and spatial density of clay open pits all over Europe. The sedimentary clays of the Tertiary partly show low shear strength. The attempt to exploit the deposits completely leads frequently to slope instability and mass movement (fig. 1), especially in association with adverse geological conditions. As a result, adjoining usages like buildings, roads, railway lines are repeatedly exposed to danger. From damage events gained experiences are documented, to optimize the planning of future surface mining projects.

Clay from the Westerwald

The Kannenbäckerland is part of the Westerwald and is located in Rhineland-Palatinate (Federal Republic of Germany). Here, up to 70 m thick clay deposits occur, that counts among the considerable mineral deposits in Central Europe because of its quality and quantity. More than 50 open pits produce about 3 million tons of clay every year. The clay was deposited during the Tertiary (65 to 2.6 million years b.p.) under continental conditions by decomposition of the 400 million year old slates of the Rhenish Massif. The deposits stand out due to their multitude and in some extent very good quality of the various clay varieties. One distinct property is the content of alumina (Al₂O₃). Common alumina-contents of Westerwald clays range from about 15 M. % („poor“ clay) to above 30 M. % („rich“ clay). The content of alumina is normally linked to the clay minerals, wherefore the plasticity and with it shear strength of the clays are determined by the alumina content. The clays of the Westerwald are mainly composed of the clay minerals illit and kaolinit plus quartz. In particular cases smectit- resp. montmorillonite-rich layers of clay occur, which feature among other things increased water absorption and lower shear strength.

Fig. 1:
Example of a slope failure in a clay open pit in the Wirges association of municipalities in Westerwald (Federal Republic of Germany) (photo: Wehinger 2002).
Case study

In Westerburg association of municipalities, during winter 2004/05 fissures appeared in a district road, that runs parallel to a clay surface mine (fig. 2). The main failure plane reaches from the middle of the road to the about 20 m lower situated ground of the surface mine. The failure plane expired approximately horizontal. In the process highly plastic clays slipped off from less plastic clays. Prior to the landslide, discharge of fluid was observed in the upper slope-area. The slope showed a general dip of about 30°. Individual slopes were up to 80° steeply tilted (fig. 3). Therefore the slope system was - especially with influx of water – too steep and not permanently stable.

After the exploration in form of field and laboratory tests, the slope failure was recalculated (fig. 4). With the thereby obtained soil properties, the rehabilitation could be dimensioned. The following activities were carried out:

Fig. 2: (up)
Fissure in the middle of the road, which runs along a clay open pit (right side in the picture) (photo: Wehinger 2005).

Fig. 3: (below)
Slope of the clay surface mine directly next to the damaged road (left in the picture). Here manual vane tests are run for the determination of the shear strength (photo: Wehinger 2005).
• The road was relocated and the level lowered (reduction of burden)
• The basement of the road was strengthened
• At the footing of the slip boxes of blocky trachyte and basalt were established. The clay was cut down up to 3 m below the failure plane and replaced by 4 m high boxes of coarse grained material.
• The slope was rebuild in a sandwich construction. Clay layers were stabilised with coarse grained material. The individual working planes were arranged staircase-shaped with a slight gradient towards clay open pit.
• Measures for the prevention of concentrated influx of surface and precipitation water into the underground were carried out.

Figure 5 shows a picture, which was taken during the rehabilitation. In figure 6 the calculated verification of the rehabilitation is documented.

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**Fig. 4:**
Recalculation of the slope failure. The security value with $\eta = 0.98$ is situated briefly below the equilibrium. Appropriate to the mining of the deposit seven different qualities of clay with friction angles of the magnitude 16 - 30 °, and cohesion $c = 5-10$ kN/m² were distinguished.

**Fig. 5:**
Slope of the clay open pit in Westerburg association of municipalities directly next to the damaged road (right side of the picture) during the rehabilitation: the slope failure masses were excavated in sections and replaced by strong material - here blocky trachyte and basalt. On the right the ground level is already lowered (photo: Wehinger 2005).
**Geotechnical experiences**

For slope failures in clay open pits of the Westerwald the following experiences can be summarized:

- Especially the base of failure planes is often bound on specified weak zones. Such weak zones can be water-bearing or water-sensitive interlayers (sandy or coal layers), clays with low shear strength, floor levels of old mining or even the boundary between very different plastic clays. During mining it is important to pay attention of such weak zones. Necessary mining can only executed in sections.

- Sliding members shows often a polygonal figure. Although clay belongs to loose rocks, cohesive material with joint faces or discontinuity leads often to sliding members which are usually seen for solid rocks.

- A lot of failures are controlled by water. The Drainage or catchment of all forms of water have high importance in prevent and also in rehabilitate of slope failures (fig. 7).

- Also for reasons of water availability the highest slide activity is record in springtime.

- For opportune conditions, this means there are only undisturbed bedded, illitic-kaolinitic clays, became from the recalculation of different slip events for equilibrium ($\eta = 1.0$) a friction angle $\varphi = 26-27^\circ$ (at cohesion $c = 0$).

- For adverse conditions, for example montmorillonitical clays or heavy water-bearing interlayers (Sand- or Lignite-bands) the calculated friction angle is $\varphi = 15-17^\circ$ or less (cohesion $c = 0$).

\[\text{Fig. 7:}\]

Examples for a slope failure in a clay open pit in Montabaur association of municipalities. Here is a street by a slide destroyed. Water from the surface flows uncontrolled into the slip and makes the stability against collapse situation also worse. (Foto: Wehinger 2007).
Soil mechanical values

In table 1 are the characteristic values of both clay varieties and their typical bandwidths. It is most notably to advert to check in every individual case the real geological and mining conditions. The given values shall provide the development of clay open pits and also plausibility checking of stability tests in a general sense.

<table>
<thead>
<tr>
<th>Clays / Parameter</th>
<th>Statistic</th>
<th>Bulk density</th>
<th>Plasticity</th>
<th>Absorptive Capacity</th>
<th>Angle of Friction</th>
<th>Cohesion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$\gamma$ [kN/m³]</td>
<td>IP [%]</td>
<td>wmax [%]</td>
<td>$\varphi^\prime$ [°]</td>
<td>$c^\prime$ [kN/m²]</td>
</tr>
<tr>
<td>Smectite Clays, tuff beds, coal clays, highly plastic clays, water-bearing or water-sensitive or disturbed interlayers</td>
<td>Characteristical value</td>
<td>18</td>
<td>30</td>
<td>90</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Typical Bandwidths</td>
<td>16-20</td>
<td>25-35</td>
<td>60-120</td>
<td>10-20</td>
<td>0-10</td>
<td></td>
</tr>
<tr>
<td>Illitic till kaolinitic clays, undisturbed bedding, lightly till highly plastic</td>
<td>Characteristical value</td>
<td>20</td>
<td>25</td>
<td>60</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>Typical Bandwidths</td>
<td>18-22</td>
<td>20-30</td>
<td>40-80</td>
<td>17-27</td>
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</tbody>
</table>

In table 1 is also the absorptive water capacity listed. Statistical analyses shows that this feature is clearly correlated with the plasticity or shear strength and the chemical-mineralogical composition. Therefore we have a relative simple experiment for the assessment of the mentioned features (fig. 8).

**Fig. 8:** Combination of the soil mechanical experimental results of Westerwald-clays from different open pits. Remarkable is the positive correlation of the aluminium-content with the plastical features.
Monitoring of opencast mine rim slopes using vertical inclinometers

by Dr.-Ing. Dieter Dahmen
Rock and Soil Mechanics. RWE Power AG | Bergheim | Germany

Background

In opencast mines, the mass removal associated with the mining process results in stress changes and, hence, deformations in the unconsolidated rock. Owing to the stratification of the rock, these deformations mainly occur in soils with low strength and in areas where strata with very different shear resistances adjoin. Since the shear resistance of soil changes with increasing deformation and may decline to a residual value, early identification of highly stressed areas is of considerable significance for the evaluation of slope stability as failure zones may develop there.

To monitor deformation behaviour, in most cases terrestrial measurements are performed on the surfaces of slopes following their completion. In addition, displacements in the rock can be measured using inclinometers. Inclinometer measurements enable information on deformation behaviour on the inside of slopes to be gained. In opencast mines they are used in particular to identify deformation active zones within rim slopes.

They allow the deformation behaviour of horizons of little shear strength for which rupture mechanisms were identified in stability calculations to be monitored and thus serve to monitor slope stability and to correlate deformations and excavation by mining equipment; in future, compared to deformation calculations, they are to permit more accurate information about the condition of a slope to be gained.

Fig. 1: Measuring principle of inclinometer
History/Development

In June 1985, vertical inclinometers were used in opencast mine slopes in the Rhenish mining area for the first time. This was done due to the large depths and the deformations to be expected in connection with square steel tubes that were installed in exploratory wells. Since 2002, well casings that can no longer be used for drainage purposes are also used for the installation of such inclinometer tubes. In the same year, an automated measurement trailer and inclinometer measuring chains for continuous monitoring of individual deformation horizons were procured. In 2005, new guide rollers for the inclinometer probes were developed, and in 2008 a semi-mobile surveillance container was purchased as replacement system and a video camera for the inspection of damage to inclinometer tubes was procured.

Special probes for measuring any torsion of the meter tubes were developed, but owing to guidance inaccuracies failed to produce consistent measuring results. The use of torsion measuring devices with gyrocompasses is currently not possible due to their large dimensions.

The square bar steel tubes in the dimensions of 110 mm x 110 mm that have been in use since 1991 are joined in a watertight manner by means of welded sleeves when they are installed. The meter tubes are mounted with the diagonal (A direction) facing in the slope’s direction of dip. The probes used at RWE Power are guided in the diagonal of the meter tube with guide rollers; they are 2 m long but can be shortened to 1 m and 0.5 m in order to enable the measurement of heavily deformed meter tubes and an increase in measurement resolution. A probe guide newly developed in 2005 prevents the probe from „getting stuck“ when it is extended. The probes are fitted with inclination sensors for the A direction (direction of dip of the slope) and the B direction, rotated by 90° in clockwise direction.

The equipment achieves a maximum accuracy of 0.1 mm/2 m; in practice 0.2 mm/2 m are attained. Since the draft of the revised version of DIN 4107-1 requires higher accuracies, opposition proceedings instigated by the German Lignite Industry Association (DEBRIV) are currently underway.

Fig. 2: Conventional (on top) and newly developed probe guide (below).
Performance of Measurements

The partially automated measurement trailer that has been in use since 2002 permits single-operator control, faster measurement and an increase in accuracy thanks to automatic positioning. In addition, the Kevlar-reinforced measuring cable is equipped with depth and induction markers.

The maximum measurement depth (measuring cable length) is 600 m; the deepest borehole ever measured so far had a depth of 498 m.

In the last 15 years a „measuring output” of 730,000 measured metres was achieved; the year with the highest „output” to date was 1994 with 97,000 measured metres.

Arrangement of Measuring Points

If inclinometer measuring points are arranged outside of the later excavation area, it is possible to monitor the deformation process over a long period of time. Inclinometer measuring points that are created in the later excavation area have to be created in accordance with the excavation progress, ploughed under (shortened) if necessary and worked over. In RWE Power AG’s opencast mines, the level and position of inclinometer wells are thus usually predetermined and the wells, if possible, sunk only once the corresponding working bench has cut free this section within the rim slope. Thus, drilling in the „open opencast mine window” and ploughing-under of the inclinometer well are not required. In addition, the lifetime of the well is optimized since the deformation that occurred within the unconsolidated rock prior to its sinking is not relevant to a well.

If, in the event of heavy deformations, the probe can no longer pass through the rectangular tube – even if shortened to 0.5 m – the exploratory well has to be abandoned and cemented.

Evaluation of Measurements

As regards evaluation, only relative movements were of interest when analogue measuring equipment was first employed (depth position of deformation horizons, differentiation between zonal and boundary plane-like deformations). Due to the limited accuracy, a threshold value of 1 mm (known as „Threshold 1”) below which the measured individual value was not taken into account was introduced for the evaluation. But this made a comparison between the movement of the top of the inclinometer tube that was measured terrestrially and the movement of the inclinometer tube top resulting from the inclinometer measurement impossible since the inclinometer result showed too little deformation. The increased precision of the digital measuring equipment in use as of 1994 allowed the threshold value of 1 mm to be dispensed with so that
today a comparison between the inclinometer tube top movement ascertained by the terrestrial measurement and that determined by the inclinometer measurement is possible. The difference of the two measurements allows the movement of the base – which in the usual evaluation is assumed to be fixed – to be deduced.

At present, 22 boreholes are measured in the Rhenish mining area, including 18 boreholes in the Hambach opencast mine (of which two are former wells), and two boreholes each in the Garzweiler and Inden opencast mines.

The measuring results are made available after the evaluation in a web-based manner on an internal data server for a selected group of users from the opencast mines and the planning departments.

When comparing the measured and calculated deformations the time reference of the deformations has to be borne in mind for the calculation since inclinometer measurements are only able to detect deformations that occur after the well has been sunk.

Fig. 4: Development of inclinometer deformation in relation to fixed base.

Fig. 5: Development of inclinometer deformation in relation to inclinometer tube top movement measured by mine survey.
Summary

Over the last 25 years, inclinometer measurements have developed into an indispensable aid to evaluating the condition and, hence, the stability of opencast mine rim slopes in the Rhenish lignite mining area.

They are used to localise the location of deformation zones and thin individual deformation horizons at an early stage.

They permit the causes of slope deformations to be identified, which makes them an important supplement to terrestrial mine surveys.

The measuring systems and evaluations were adapted to the special requirements and underlying conditions at RWE Power and are subject to continuous development.
Slope failure usually occurs when the shear strength of the in-situ material is weakened by one or more factors (e.g. geometrical, geological and hydrological conditions), or when external driving forces are greater than the internal holding forces. In hard rock, stability problems are mainly due to sliding on predetermined slip-surfaces. Besides sliding there is also the possibility of tipping to be considered. The zones of weakness are formed by the existing fracture system in the rock mass. Besides classical slope failures there is a danger of liquefaction in water-saturated areas, the sudden transition from a solid to a liquefied state. The structural collapse, for example of an embankment with its base submerged in water, usually causes the failure of the entire overlying dry slope. The resulting rapid momentum is acutely life-threatening. In the past, this has resulted in more than a dozen fatal accidents in the lignite mining industry, but risks are present in non-metallic minerals mining too. Particularly vulnerable are areas where non-useable fine sediments are dumped back in the pit during the wet-extraction process. Due to their particle size distribution, the loose density and degree of water saturation, they are at particular risk for liquefaction events.

Rehabilitation can be carried out on unstable slopes by making changes to the geometry (flattening and setting up berms), cut at the top of the slope; fill at the base or by technological or biological supporting measures. Rehabilitation is usually very complex, costly, and can only be partially implemented during ongoing open pit operation. Hence, for reliable monitoring of slopes in opencast mines the use of advanced monitoring systems is recommended. In the short term this can quickly provide answers to questions like: Where is the groundwater in the slope? Are slope movements occurring? Which precautions must be taken? In the past, such issues could only be resolved by using time consuming field measurements, monitoring and evaluation campaigns. The results of such measurements usually came too late, as many past accidents show.
Today modern internet-based applications can ease this situation. Within a short space of time, automated answers to the questions posted above can be delivered in real-time. Such systems ensure that all the relevant parameters and their trends can be quickly visualised and analysed graphically.

Web-based systems transform data from sensors and measuring points in the field into concise visual information. Data from various devices and sensors, such as total stations, inclinometers, extensometers, piezometers, GPS, webcams, borehole sensors, meteorological instruments, etc. can be collected and retrieved in real time from anywhere in the world.

In recent years FUGRO CONSULT GMBH has developed the GeODin software platform into an automated system for managing data of a pre-installed monitoring network, which has been successfully employed in several complex slope and hillside monitoring projects.

In simple terms such systems work as follows: In a typical surveillance area any number of sensors will be installed. The sensors measure pre-defined parameters at regular intervals and produce files in ASCII format. These files are transferred to a locally installed PC in the field.

The files on the field PC are copied at regular intervals to an FTP server and for data security also stored as zip archives on the PC in the field. The data is then collected from an FTP server and after passing a series of “Thresholds“ tests automatically written to various tables in a database. If necessary, and depending on the actual values measured, both pre- & post-processing can

![Fig. 2: Screenshot of a web based monitoring system with different sensor types](image-url)
be carried out on the original data to produce additional virtual parameters that can be stored in the database too.

The GeODin Portal Server presents this data by creating a series of interlinked web-pages in real time on the basis of the information currently available in the database. The web pages are GeODin layouts produced “on-the-fly” and viewable in any web browser. The individual web pages can contain a wide range of graphic types (tables, lists, time-series, trend lines, XY plots, variable text elements etc.), as well as images (photos, logos) all of which can be interlinked within the portal and to map server applications.

The GeODin platform enables the creation of complete web portals to present your data. This can be done without knowledge of HTML programming or web design. Furthermore, you can extend the functionality of the GeODin Portal Server through the use of other server-side (PHP, ASP) or client-side (JavaScript) technologies.

In addition, a function for ad-hoc creation of reports in PDF format is included.

For example, visitors to your web portal can be provided with the complete documentation of a borehole. This can be spread over several individual layouts such as a header page, a summary log and a well design profile as well as providing a link to download the complete report on the borehole on this hole as a PDF file. An important safety feature is the ability to run the database scripts that control the alarm functions. These critical parameters can be freely defined and you can also specify which events trigger what kind of alarm (a text message and / or an e-mail) to be sent to specific persons responsible. The sending of periodic reports to selected recipients is also included.

It is important that these systems can be customised to the individual needs of mining operations. Their usefulness demands that they provide a generic solution, universally adaptable, without restrictions and easily expandable for...
the future. Of course, with all the configuration possibilities and 24/7 accessibility, the security of sensitive data and its protection from unauthorised access is guaranteed. Hence for mining operations the GeODin platform presents a useful and relatively inexpensive range of tools, both to meet growing security concerns, whilst at the same time preventing economic down-time and so minimising financial losses.

FOR MORE INFORMATION AND CONTACT:

FUGRO CONSULT GMBH
Thomas Graf
Fachbereichsleiter Bergbau/Infrastruktur
Wolfener Strasse 36V
12681 Berlin | Germany
Tel.: +49 (0) 30 93 - 651 - 331
Fax: +49 (0) 30 93 - 651 - 300
eMail: T.Graf@fugro.de
Internet: www.fugro.de

Fig. 4:
Simplified flowchart showing the way of the data from the collection in the field to the web based monitoring platform
Geotechnical investigation and evaluation
The basis for slope stability analysis

by Dirk Bruhn
Terra Control GmbH | Bad Nauheim | Germany

Modern geotechnical software for the analysis and construction of slopes in soft and hard rocks are easy to use and produce fast results. Our experience of the last decade shows that this situation leads to an overall underestimation of the complexity of slope stability analysis. In this paper an example of a small scale excavation in argillaceous slates emphasizes the importance of comprehensive geotechnical site characterizations.

In the city of Usingen a sports hall with a basement car park had been planned adjacent to the existing swimming hall. According to the data of the geologic map and earlier construction sites in the vicinity the excavation for the building would cut through an unconsolidated overburden soil consisting of an argillaceous loam, the residual product of the argillaceous slates, and in the underlying lower Devonian argillaceous slates of the Emsstufe. According to previous experiences the weathering of the argillaceous slates can reach several meters deep and transform the shales to a soft rock underlying the clayey residual loam.

The structural setting of the lower Devonian slates is dominated by a southwest/northeast striking fold structure typical for the Rhenish massif.

The folded bedding is dissected by a closely spaced cleavage and different generations of faults.

In similar structural and geological settings excavations in argillaceous slates had been shaped with an angle of slope of 70° for temporary slopes (construction sites).

The geotechnical site characterization based on an investigation program of two test pits, six dynamic penetrations for core sampling and two DPG (dynamic probing giant) with a 200 kg ram body. The results of the investigation confirmed the assumed geological setting mentioned above.

Under an overburden of residual soil with thickness of 3 to 5 m the lower Devonian argillaceous slates are weathered to “soft rock”. The transition zone to the less weathered slates reached down to 7.5 m below the surface.

The orientation of the north slope of the excavation is intersecting the structural geological setting with an angle of 10°. The excavation was situated in the rising flank of a regional northwest vergent fold structure. The bedding and the cleavage of the slate display the same direction of dip whereas the inclination for the cleavage is slightly steeper than of the bedding. Bedding and cleavage planes are inclined between 65° to 80°.

The evaluation of the investigated data showed that an economic but save angle of slope for the residual loam would be 50° and for the lower Devonian slate would be 70°, divided by a berm of 1 m width. For an economic management of the uncertainty imposed by possible inhomogeneous zones in the rock the contractor was advised to develop the excavation from South to North over the complete excavation height together with a daily monitoring of the structural and geological setting of the northward excavation slope and the excavation level.

For economic reasons and due to a tight timing the excavation work didn’t follow that advice. Closely before profiling the final north slope of the excavation pit several slope failures of the 8 meter high slope occurred.

The immediate survey of the situation found that the pit level was completely masked by the tracks of the excavator and dumpers. So no daily monitoring had been carried out, making an in-time adaption of the excavation slope impossible.

The investigation of the structural and geological situation unveiled a rather complex interplay of several...
Fig. 1: On this sheer planes compact parts of the excavation slope with thicknesses around 1 m slid down to the pit level.
limiting structural parameters. Along the north slope several small scale duplex structures (fig. 1) could be identified. The duplex structure by definition is confined within sheering planes, thereby giving evidence of a sheer zone within the slates. Further investigation showed that these sheer zones were activated by subsequent faulting processes. They possess an inclination of 42° to 50° and a southern dip direction parallel to the slope.

The slope parallel orientation of the sheer zone together with the intensively disturbed material had been identified as the main reason for the slope failure. On this sheer planes compact parts of the excavation slope with thicknesses around 1 m slided down to the pit level (fig. 2).

After cleaning the pit level another major structure was identified. A large scale water bearing fault dissected the Devonian slates, intersecting the north slope on its western corner. This major fault displayed a massif alteration of the neighbouring rocks (fig. 3).

The plastification of the slates and the deformation zones of this major fault could be traced several meters into the surrounding slate, altering the western parts of the North slope (fig. 4).

Fig. 2:
On this sheer planes compact parts of the excavation slope with thicknesses around 1 m slided down to the pit level.
The evaluation concluded that the mentioned structural and geological features degenerated the rockmechanic parameters to $\phi = 14^\circ$ and $c = 5 \text{kN/m}^2$ under the direct influence of the strongly altered slates and to $\phi = 21^\circ$ and $c = 8 \text{kN/m}^2$ within the little altered parts of the slope. The stability analysis of the data resulted in the construction of a rock-nail back anchored $60^\circ$ slope of the North slope.

After profiling the North slope of the pit with a final $60^\circ$ angle the anchoring holes were drilled with an excavator operated Morath drilling system utilizing a down hole hammer rod. The insertion of the rock-nails and the grouting work were carried out from a lifting platform to guarantee a safe working distance to the $60^\circ$ slope for the duration of the anchoring work.

This example shows the importance of a comprehensive characterisation and geotechnical monitoring in complex geological situations.

A continued monitoring and – in geotechnical terms – sensitive excavation could have saved time and money.

Fig. 3: The major fault displayed a massif alteration of the neighbouring rocks.
Fig. 4: The plastification of the slates and the deformation zones of this major fault could be traced several meters into the surrounding slate, altering the western parts of the North slope.

FOR MORE INFORMATION AND CONTACT:

Terra Control geologische Beratung und Umwelttechnik GmbH
Dirk Bruhn
Bad Nauheimer Straße 19
61231 Bad Nauheim | Germany
Tel.: +49 (0) 60 32 - 971 - 355
Fax: +49 (0) 60 32 - 971 - 357
eMail: bruhn@terra-control.de
Internet: www.terra-control.de
Consideration of earthquakes in stability calculations for deep underwater final slopes

by Dr. Michael Goldscheider¹, Dr. Dieter Dahmen², Dr. Christian Karcher²
¹formerly Institute of Soil Mechanics and Rock Mechanics, Univ. of Karlsruhe, retired
²Rock and Soil Mechanics, RWE Power AG | Bergheim | Germany

Introduction to problem and solution methods

The typical final slope of an opencast mine in the Rhenish lignite mining area, the stability of which this article deals with, is about 100 to 300 m deep and cuts into unconsolidated rock formed by several horizontal to slightly inclined soil strata (Figure 1). These strata differ in terms of their granularity, density, water permeability and in terms of the effective shear parameters \( \phi' \) and \( c' \). Often, there is a clay layer with very low shear resistance just below the base of the slope. The state in which the slope partly submerges into a lake has to be analyzed. The groundwater table in the slope body is assumed to be horizontal and at the level of the open water table. In addition, the fact that the slope might be subject to seismic accelerations with a horizontal and a vertical component

\[
a_h = \alpha_h \cdot g; \quad a_v = \alpha_v \cdot g \quad \text{Term (1)}
\]

has to be taken into account (g acceleration of gravity, \( \alpha_h \) and \( \alpha_v \) relative horizontal or vertical ground acceleration as a result of an earthquake). The values for seismic accelerations were determined by engineering-seismic investigations conducted at the Bensberg Earthquake Station of Cologne University [1] and are given quantities for our analysis. The calculation is performed on the basis of this data using the following values – including an admissible reduction to allow for slopes: \( a_h = 0.5 \, \text{m/s}^2 \), \( a_v = 0.35 \, \text{m/s}^2 \), duration of strong ground movements about 5 s (in the case of quasi-static calculation methods, only 50% of the accelerations must be considered according to [3]; \( a_h = 0.5 \, \text{m/s}^2 \) und \( a_v = 0.35 \, \text{m/s}^2 \) are the values from the engineering-seismic investigations reduced to 50%).

The task this article reports on consists in developing methods for calculating the resistance of such slopes against deep-reaching slope slides under the above-mentioned influences. A slope slide is regarded as a plastic failure, with the analysis being restricted to the plastic limit state. Deformations are not calculated within the scope of this part of the investigations.

The classic method of stability calculation according to the plasticity theory is based on the kinematics of failure, i.e. the so-called rupture mechanism that has to be assumed by virtue of observation and experience taking certain principles into consideration. For this rupture mechanism, the force distribution in the limit equilibrium is determined.

Within the scope of our investigations regarding the deep final slopes, we tested the approaches to complex rupture mechanisms and to slip circles on the basis of the slice method in theory and adapted them to the existing special conditions. Complex rupture mechanisms are formed by several sliding bodies which, in the calculation, may be assumed to be rigid in themselves and which are able to move relative to each other and to their rigid surroundings along straight inner and outer slip lines (examples in Figure 2). Principles for the design and calculation of such rupture mechanisms are described in [2]. Complex rupture mechanisms are ideally suited to reproduce the characteristics of the stratification, slope geometry and influences.

Fig. 1: Given situation: Deep, stratified slope that submerges into a lake. (a) to (f) strata
This article restricts itself to explaining the effects of seismic forces on the ground and their application in the slice method for slip circles according to Bishop (Figure 3). DIN 4084, which deals with this slip circle calculation method, does not contain any information about the consideration of seismic forces. Our approaches presume that the grain structure is not changed by the seismic accelerations; thus they do not apply to severe earthquakes and very loose soils. In principle, the same assumptions about earthquake effects apply to complex rupture mechanisms, but the static calculation is a bit more difficult because the simplifying static assumptions of the Bishop method are not used.

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**Fig. 2:**
Examples of complex rupture mechanisms formed by several sliding bodies and straight slip lines in longitudinal section [2].

**Fig. 3:**
Example of a slip circle with water pressures and slice division; coordinates and notations.
Statics of slip circle slices according to Bishop

Fig. 4: Statics for a slice in area C of the slip circle. (a) Slice with all acting forces including seismic forces. (b) Polygon of forces for limit equilibrium in state without earthquake. (c) Polygon of forces for limit equilibrium in state with seismic forces and with vertical component $D V_i$ pointing downwards. (d) like (c), but with vertical seismic force pointing upwards $D V_i$. 

(a) 

(b) 

(c) 

(d)
Statics of slices without seismic forces

In the slice method used to calculate slip circles, the sliding body is cut into vertical slices (Figure 3). This cutting into slices is done in order to – via static assumptions and the equilibrium conditions for the various slices – obtain a statically admissible solution for stress distribution along the slip line, which is statically indeterminate. A solution for stress distribution is required because protection against slope failure with a curved slip line in non-cohesive soil depends on stress distribution. The static assumptions to be introduced refer to the forces in the vertical sections that have been cut free. The static calculation is performed for an imaginary limit equilibrium condition, with the effective limit condition for the various layers

\[ \tau'_i = c' + \sigma' \tan \phi' \tag{2} \]

being used for the calculation; \( c' \) and \( \sigma' \) refer to the characteristic values of the shear parameters in accordance with the safety concept used for opencast mine final slopes.

In the slice method according to Bishop on which this calculation is based, the forces in the vertical sections are assumed to be horizontal. In addition, the requirements resulting from the moment equilibrium condition for the various slices are disregarded.

Let \( n \) be the number of slices and \( i \) with \( 1 < i < n \) the running number of the slices. The slice width is \( b_i \) and its angular coordinate \( \theta_i \), with \( \theta_i \) being determined by the radius vector of the intersecting point of the vertical bisecting line of the slice with the slip circle (Figure 4 a). For the further analysis it is sufficient to take a look at a slice from area C of Figure 3 where the slope surface is below the lake’s water table. In intermediate area B the water pressures \( w_i \) on the slope surface and in upper area A all water pressures \( u_i \) on the inner edges do not occur. Figure 4 a shows the forces acting on a slice in area C in the above-mentioned conditions. In particular due to the different effects of the seismic forces on the water pressures in the soil, the water pressures – as in DIN 4084 – are taken into account by assuming water pressures to act on all edges of a soil element in connection with the total soil unit weight instead of with the seepage forces and the effective unit weight; though the latter approach would also be possible. In the absence of an earthquake, the following forces thus act on a slice:

1) The total force of gravity \( G_i \), calculated below the water table with the (total) unit weight \( \gamma_r \) of the water-saturated soil and above the groundwater table with the unit weight \( \gamma \) of the moist soil. For the sake of simplicity, the lines of influence of \( G_i \) are assumed to be independent of the form of the slice.

2) The hydrostatic water pressures \( u \) on the slip line segment and the vertical slice edges and \( w \) on the free slope surface; they are calculated using the formulas

\[ u = \gamma \cdot h_u, \quad w = \gamma \cdot h_w; \tag{3} \]

where \( h_u \) is the specific weight of the water and \( hu \) and \( hw \) the vertical height of the water table above the point of application of \( u \) and \( w \) (Figures 1 and 4 a); the water pressures are combined in resulting forces acting vertically on the affected edges; thus, the resulting water pressure force,

\[ U_i = u_i \cdot b_i / \cos \phi_i; \tag{4} \]

acts on the slip line segment, with \( u_i \) being the average water pressure in this slip line segment and \( U_i \) being assumed to be inclined to the vertical at the angle \( \phi_i \); on the slope surface, the components

\[ W_{i_{xz}} = w_i \cdot b_i, \quad W_{i_{xx}} = w_i \cdot \Delta h_i; \tag{5} \]

act (\( \Delta h_i \) see Figure 4 a). The resulting water pressure forces on the two vertical slice edges are \( U_{i_{i-1}} \) and \( U_{i_{i+1}} \), but these do not need to be calculated if the water table is horizontal since they balance each other.

3) The resulting effective normal force \( N'_{i} \) with \( N' \) – as with \( U_i \) – being assumed to be inclined to the vertical at \( \phi_i \), i.e. acting on the intersecting point of the vertical bisecting line of the slice with the slip circle.

4) The resulting shear resistance \( T_i \) in the slip line segment; it has to reach an imagined limit equilibrium condition, which is achieved by the following approach:

\[ T_i = R_i / \eta_F, \tag{6} \]

with the following applying in accordance with the boundary condition (2)

\[ R_i = c' \cdot b_i / \cos \phi_i + N' \cdot \tan \phi_i; \tag{6a} \]
in equation (6) \( \eta_p \) is an unknown factor that is the same for all strata and slices and that has to be determined such that an equilibrium is established between the \( T_i \) according to equation (6) and the given acting forces. \( \eta_p \) signifies a global stability coefficient and is called 'stability coefficient according to Fellenius'. Instead of with \( \eta_p \), equation (6) may also be written using the exploitation factor of the shear resistances defined in DIN 4084. The point of application of \( T_i \), as that of \( N'_i \), is assumed to be in the intersecting point of the vertical bisecting line of the slice with the slip circle and the inclination of \( T_i \) is assumed to be in the direction of the tangent in this point, i.e. at angle \( \phi_i \) to the horizontal.

5) The forces in the vertical slice edges (earth pressures) \( E_{i,i-1} \) and \( E_{i,i+1} \), which are assumed to act horizontally, meaning that, under all kinds of directional assumptions, shear resistance is exploited the least in these sections.

To simplify the static calculation, the moment equilibrium condition for each individual slice is left aside; only the two force equilibrium conditions are considered. The assumptions with regard to the application points and directions of forces \( G_i, U_i, N'_i \) and \( T_i \) mentioned above in the list of forces correspond to this static simplification. The moment equilibrium condition for an individual slice might, inter alia, require an eccentric position of the joint application point of \( T_i \) and \( N'_i \). Thus, the angle of inclination of these forces would change, which would have an effect on the equilibrium of forces and, as a result, on the magnitude of the unknown forces. On the other hand, the establishment of the moment equilibrium for every slice is generally not possible without creating discontinuities in the stress distribution that are physically impossible. Static approximations are inevitable if the slip circle problem is to be solved and certain inaccuracies have to be accepted since the slip circle is generally not the exact solution to the plastic problem.

Neglecting the moment equilibrium, the following equations are available for every slice \( i \), \( 1 < i < n \):

1) The limit condition for effective stresses, equation (2), including the unknown global safety coefficient \( \eta_p \) according to Fellenius: for the forces acting on a slice according to Figure 4 a, the limit condition leads to equations (6) and (6 a):

\[
T_i = \frac{1}{\eta_F} \cdot R_i = \frac{1}{\eta_F} \left( \frac{G_i + b_i \cdot (w_i - u_i) - T_i \cdot \sin \phi_i - N'_i \cdot \cos \phi_i}{\cos \phi_i} \right). \quad \text{Term (7)}
\]

2) Equilibrium of vertical forces

\[
\sum_j V_{ij} = G_i + b_i \cdot (w_i - u_i) - T_i \cdot \sin \phi_i - N'_i \cdot \cos \phi_i = 0. \quad \text{Term (8)}
\]

3) Equilibrium of horizontal forces

\[
\sum_j H_{ij} = u_i \cdot b_i \tan \phi_i - w_i \Delta h_i + U_{i,i-1} - U_{i,i+1} - T_i \cos \phi_i + N'_i \sin \phi_i + E_{i,i-1} - E_{i,i+1} = 0. \quad \text{Term (9)}
\]

where slice forces \( E_{i,i-1} \) and \( E_{i,i+1} \) acting in the vertical section between two slices are opposite and equal. In the case of the horizontal water table presumed here, the resultant force of the horizontal components of all water pressures on a slice equals zero:

\[
u_i b_i \tan \phi_i - w_i \Delta h_i + U_{i,i-1} - U_{i,i+1} = 0,
\]

which simplifies equation (9) as follows:

\[
\sum_j H_{ij} = -T_i \cos \phi_i + N'_i \sin \phi_i + E_{i,i-1} - E_{i,i+1} = 0. \quad \text{Term (9a)}
\]

Equations (7) to (9)/(9 a) for the \( n \) slices form a system of \( 3n \) non-homogeneous equations. The unknowns are: the \( n \) slip line forces \( T_i \) and \( N'_i \), the \( n-1 \) section forces \( E_{i,i+1} \), \( 1 < i < n-1 \), and the global safety coefficient \( \eta_p \), hence a total of \( 3n \) variables. Thus, all unknowns can definitely be determined with this system of equations. But the system is non-linear in \( \eta_p \), so that \( \eta_p \) can only be calculated in an iterative manner. If \( \eta_p \) is known, the remaining, now linear equation system can explicitly be solved for the other unknowns. The polygon of forces shown in Figure 4 b is the graphic solution of these equations for a slice with an assumed value for \( \eta_p \); drawing the force polygons for all slices next to each other would yield the full solution. The usual application of the Bishop method is restricted to the determination of \( \eta_p \) or of the exploitation factor of the shear resistances.

To determine \( \eta_p \) from equations (7) to (9), the following procedure is usually followed: in equation (8) \( T_i \) is replaced by the expression of equation (7) and this equation is solved for \( N'_i \), which produces the expression

\[
N'_i = \frac{G_i + b_i \cdot (w_i - u_i) - \frac{1}{\eta_p} \cdot c_i b_i \tan \phi_i}{\sin \phi_i + \cos \phi_i}. \quad \text{Term (10)}
\]

this expression for \( N'_i \), equation (10), is inserted into equation (7), which is then solved for \( R_i \):

\[
R_i = \frac{G_i + (w_i - u_i) b_i \tan \phi_i + c_i b_i}{\frac{1}{\eta_p} \tan \phi_i \cdot \sin \phi_i + \cos \phi_i}. \quad \text{Term (11)}
\]
The equilibrium conditions for the horizontal forces could be used by first adding up the equations for all slices, which would lead to the omission of the slice forces $E_{xi}$, $1 < i < n$; but this equation sum would still contain $U_i$ and the unknowns $N'_i$. An even more convenient equation is obtained by using the sum of the moments around the centre of the slip circle according to the suggestion by Bishop instead of the sum of the equilibrium equations for horizontal forces. This equation is as follows:

$$\sum_{i=1}^{n} M_i = r \cdot \sum_{i=1}^{n} \left( G_i + w_i h_i \right) \sin \vartheta_i - \left| M_{wi} \right| - r \cdot \frac{1}{\eta_F} \cdot \sum_{i=1}^{n} R_i = 0;$$

Term (12)

with $|M_{wi}| = W \cdot x \cdot d_i$ being the moment of the horizontal component of the total water pressure on the slope surface around the centre of the slip circle. Transforming equation (12) yields the implicit equation for $\eta_F$:

$$\eta_F = \frac{r \cdot \sum_{i=1}^{n} R_i}{r \cdot \sum_{i=1}^{n} \left( G_i + w_i h_i \right) \sin \vartheta_i - W \cdot d_i}.$$  

Term (13)

by means of equations (13) and (11) $\eta_F$ is determined in an iterative manner, beginning with an estimated value $\eta_F$.

It should be noted that $\eta_F$ could also be determined in an iterative manner via the equilibrium condition of the horizontal forces in equation (9), with this $\eta_F$ value generally differing from the value according to equation (13) despite having the same definition. The difference between the two $\eta_F$ values is due to the unavoidable defect in the moment equilibrium for the various slices, which has a different effect on both modes of calculation, based on equation (9) and equation (13). The typical mode of calculation, which is specified in DIN 4084, is the mode based on equation (13), but this is mainly due to historical reasons.

**Introduction of seismic forces into the static calculation of slices**

The decisive static assumption of the slice method according to Bishop, namely that the forces in the vertical sections are horizontal, is applied to the case with earthquakes as well.

The forces resulting from seismic accelerations are inertia forces occurring alternately in opposite directions. As regards slopes, both conditions with maximum inertia forces, upwards and downwards, have to be examined for the vertical component; for the horizontal component only the condition with maximum inertia forces away from the slope (in positive x direction as shown in Figure 3) is of significance. It is assumed that the conditions with maximum horizontal and vertical acceleration coincide. The inertia forces in the direction under consideration are treated as monotone static loads with short-term effects. The accelerations have a uniform effect on all masses contained in the sliding body, i.e. also on the mass of the grain skeleton of the soil and on the mass of the pore water contained in the soil. In addition, the fact that seismic forces, as they develop very quickly, may create excess or negative pore water pressures depending on the hydraulic conditions of the soil is considered. The seismic accelerations also have an effect on the open water in that they create long waves in the lake; these are taken into account by a temporary level change of the open water while the groundwater table remains the same (previously assumed: temporary lowering of water table by $D_{Fw} = 0.20$ m simultaneously with a condition of maximum ground accelerations).

The assumption of different acceleration values for different areas of the sliding body does not pose any problems in the application of the developed formulas.

It again suffices to analyze a slice in area C of Figure 3. Figure 4 a shows the slice with all acting forces. The following forces are added to this by seismic impact:

**Additional inertia forces:** The vertical and horizontal components $\Delta V_i$ and $\Delta H_i$ of the seismic force are added to the total force of gravity $G_i$. These components amount to:

$$\Delta V_i = \pm \alpha_v \cdot G_i \quad \text{Term(14)}$$

$$\Delta H_i = \alpha_h \cdot G_i \quad \text{Term(15)}$$

In equation (14), the positive sign $\Delta V$ means downwards, the negative sign $\Delta V$ upwards; in Figure 4 $\Delta V$ is signified by $\Delta V^+$ for upwards and $\Delta V^-$ for downwards. The horizontal component $\Delta H$ is exclusively assumed in the slope’s direction of dip, i.e. to the left and in positive x direction in the considered situation. In the force polygons in Figures 4 (c) and (d) the three forces $G_i$, $\Delta V_i$ and $\Delta H_i$ have been combined in their resultant force $F_i$ (dashed). $\Delta V_i$ and $\Delta H_i$ as $G_i$ act on the slice’s centre of mass, i.e. approx. at half height, $a_i / 2$, of the slice.
Change in hydrostatically caused pore water pressures: Since the seismic acceleration has an effect on the pore water as well, all pore water pressures in the soil, just as \( G \), are changed by the factor \( 1 + \alpha_y \) i.e. instead of with equation (3), pore water pressures \( u_i \) in the slip line are calculated by means of the relation

\[
u_i^\pm = \gamma_w \cdot (1 \pm \alpha_y) \cdot h_i\], \quad \text{Term (16)}
\]

where \( h_i \) is the depth below the unchanged groundwater table. The water pressures \( u_i \) in the soil are not changed by the horizontal component of the seismic acceleration because the inclination of the groundwater table is not altered by the seismic acceleration. The resulting water pressure forces \( U_i^\pm \) in the slip line section are again calculated from the water pressures according to equation (16) using equation (4).

\( U_i^\pm \) and \( U_i^\pm \) in the lateral slice edges do not need to be calculated since, being internal forces, they can be omitted from the equilibrium conditions.

Excess pore water pressures:

The seismic forces \( \Delta V_i \) and \( \Delta H_i \) lead to quick changes \( \Delta N_i \) in the total normal forces in the slip line and these in turn result in excess and negative pore water pressures \( \Delta U_i \) additionally to the hydrostatic water pressures according to equation (16). The \( \Delta N_i \) and thus the \( \Delta U_i \) are not obtained as unknowns from the system of equilibrium equations for the slices; they have to be predefined just as the hydrostatic water pressures or determined in advance by other considerations. But due to the assumed horizontality of the slice forces, the following simple and adequately accurate approximation can be given: one imagines the seismic forces \( \Delta V_i \) and \( \Delta H_i \) combined in their resultant force \( \Delta F_i \), and splits \( \Delta F_i \) into components \( \Delta T_i \) and \( \Delta N_i \) parallel and normally to the median tangent of the slip line section; these components are:

\[
\Delta T_i^\pm = \Delta V_i^\pm \sin \vartheta_i + \Delta H_i \cos \vartheta_i, \quad \text{Term (17)}
\]

\[
\Delta N_i^\pm = \Delta V_i^\pm \cos \vartheta_i - \Delta H_i \sin \vartheta_i = G_i \cdot (\pm \alpha_y \cos \vartheta_i - \alpha_h \sin \vartheta_i), \quad \text{Term (18)}
\]

The polygons of forces in Figures 4 (c) and (d) show the splitting according to equations (17) and (18). Due to the horizontal slice forces, equations (17) and (18) hold exactly for the slices whose slip line segment is horizontal; in the case of the other slices, some of the force \( \Delta N_i \) calculated according to equation (18) is supported by the difference in slice forces.

If the slip line section is situated in water-saturated or at least partially saturated soil, the normal component \( \Delta N_i \) becomes a share \( p_u \) in excess pore water pressure

\[
\Delta U_i^\pm = p_u \cdot \Delta N_i^\pm
\]

\[
= p_u G_i \cdot (\pm \alpha_y \cos \vartheta_i - \alpha_h \sin \vartheta_i), \quad \text{Term (19)}
\]

and is converted into an effective normal force with the rest:

\[
\Delta N_i^\prime = (1 - p_u) \cdot \Delta N_i^\pm, \quad \text{Term (20)}
\]

(In the case of \( \Delta N_i >0 \) according to equation (18), \( \Delta U_i \) according to equation (19) is an excess pore water pressure force that acts on the slices in the direction of the slip circle centre, as in Figure 4 c; otherwise a negative pore water pressure force, i.e. a tensile force as in Figure 4 d).

The numerical value of the factor \( p_u \) in equation (19) depends on the water permeability and on the degree of saturation of the soil surrounding the sliding plane. Until more precise information is available, the following estimated values are used for the calculation:

- **Slip line below the groundwater table**: \( p_u = 1.0 \) in all soils occurring near the final slopes of RWE Power’s opencast mines
- **Slip line above the groundwater table**: soil at the slip line
  - Sand or gravel: \( p_u = 0 \)
  - Clay or silt: \( p_u = 0.7 \) bis 1.0 depending on degree of saturation

Reduction in lake water pressure on the slope surface:

In the case of a slice in area C, the quick decline of the water table by the height \( h_{w} \) assumed as a result of long waves leads to a change in water pressures \( W_{w} \) by \( \Delta W_{w} = \Delta W_{w} \) and \( \Delta W_{w} \) with

\[
\Delta W_{w} = \gamma_w \cdot \Delta h_{w} \cdot b_i = \Delta w \cdot b_i, \quad \text{Term (21)}
\]

upwards

\[
\Delta W_{w} = \gamma_w \cdot \Delta h_{w} \cdot \Delta h_{w} = \Delta w \cdot \Delta h_{w}, \quad \text{Term (22)}
\]

away from the slope in horizontal direction

with \( Dw = g_w \cdot D h_w \) and \( \Delta h_i \) according to Figure 4a.
Introduction of seismic forces into the equilibrium conditions:

The forces generated by earthquakes, i.e. $\Delta V_i$ and $\Delta H_i$ according to equations (14) and (15), $U_i$ according to equation (16) instead of equation (3), $\Delta U_i$; according to equations (19) and (18), and $\Delta W_i$ and $\Delta W_i'$ according to equations (21) and (22), are now inserted into equilibrium equations (8), (9) and (12) in addition to/instead of the forces acting continuously, with the assumptions regarding the direction of the forces on the vertical edges (horizontal) and the lines of acting of the slip line forces $N_i'$ and $T_i$ remaining unchanged.

Thus, the equation for the limit condition, equation (7), still applies.

Equation (8) for the equilibrium of the vertical forces becomes

$$\sum_j Y_j = G_s \cdot \left(1 + \cos \theta_i\right) + h \cdot \left(w_i - \Delta w - u_i^0\right) - T_i \cdot \sin \theta_i - \left(N_i' + \Delta U_i\right)\cos \theta_i = 0;$$

Term (23)

with the seismic forces, equation (9) for the equilibrium of the horizontal forces becomes

$$\sum_j H_j = \alpha_i \cdot G_s - \Delta U_i \sin \theta_i + \Delta W_i - \left(U_{i-1} - U_{i+1} - W_i - U_i \sin \theta_i\right);$$

Term (24)

$$-T_i \cdot \cos \theta_i + N_i' \sin \theta_i + E_{i-1} - E_{i+1} = 0$$

since the horizontal water pressures balance each other out due to the horizontal water table

$$U_{i-1} - U_{i+1} - W_i - U_i \sin \theta_i = 0 \quad \text{Applies, hence equation (24) is simplified to}$$

$$\sum_j H_j = \alpha_i \cdot G_s - \Delta U_i \sin \theta_i + \Delta W_i - T_i \cdot \cos \theta_i + N_i' \sin \theta_i + E_{i-1} - E_{i+1} = 0$$

Term (24a)

Excess pore water pressures in the slices, which may be caused by the seismic forces, are contained in $E_i$ as they are not explicitly taken into account in equation (24).

Solving of the equations and determination of $\eta_F$

The polygons of forces shown in Figures 4c and d are the graphic solution to equations (23) and (24) or for a slice if a $\eta$ value has been selected. The 3n equations (7), (23) and (24)/(24 a) would allow the global safety coefficient $\eta_F$ (or the exploitation factor of the shear resistances) and, in addition, all unknown forces to be determined. But in order to adhere to the usual method of calculation employed to determine $\eta_F$, instead of the equilibrium conditions for the horizontal forces the global moment equilibrium condition is again used. To this end, the equation (23) is solved for $N_i'$ following the insertion of (7), which, instead of equation (10), produces the expression

$$N_i' = \frac{G_s \cdot \left(1 + \cos \theta_i\right) + h \cdot \left(w_i - \Delta w - u_i^0\right) - \frac{1}{\eta_F} \left[c \cdot \tan \theta_i - \sin \theta_i \cdot \cos \theta_i\right]}{1 - \frac{1}{\eta_F}\tan \psi_i \cdot \sin \theta_i + \cos \theta_i}$$

Term (25)

Inserting equation (25) into equation (7) yields the following expression instead of equation (11)

$$R_i = \frac{G_s \cdot \left(1 + \cos \theta_i\right) + h \cdot \left(w_i - \Delta w - u_i^0\right) - \frac{1}{\eta_F} \left[c \cdot \tan \theta_i - \sin \theta_i \cdot \cos \theta_i\right]}{1 - \frac{1}{\eta_F}\tan \psi_i \cdot \sin \theta_i + \cos \theta_i}$$

Term (26)

the global equilibrium of moments around the slip circle centre, instead of equation (12), yields the equation

$$r \cdot \sum_i \left[G_s \cdot \left(1 + \cos \theta_i\right) + h \cdot \left(w_i - \Delta w - u_i^0\right)\right] \sin \theta_i + \sum_i G_s \cdot \alpha_i \cdot \alpha_i - \sum_i \left(w_i - \Delta w\right) \cdot \Delta H_i \cdot \alpha_i =$$

$$= r \cdot \frac{1}{\eta_F} \sum_i R_i \quad k = j + m + 1$$

Term (27)

(for the meaning of the numbers j and m see Figure 3); converting equation (27) transforms it into the implicit equation for $\eta_F$, which replaces equation (13)

$$\eta_F = \frac{r \cdot \sum R_i}{r \cdot \sum \left[G_s \cdot \left(1 + \cos \theta_i\right) + h \cdot \left(w_i - \Delta w - u_i^0\right)\right] \sin \theta_i + \sum G_s \cdot \alpha_i \cdot \alpha_i - \sum \left(w_i - \Delta w\right) \cdot \Delta H_i \cdot \alpha_i}$$

Term (28)

By means of equation (28), $\eta_F$ is determined iteratively in the usual manner. ★
Summary

Seismic accelerations with horizontal and vertical components have multiple effects on a slope. They generate additional inertia forces of the soil that spread over the grain skeleton and the pore water proportionally to the percent by weight. The vertical accelerations change the hydrostatically caused pore water pressures. The changes in total stresses resulting from these additional forces and pressures are partially or fully transformed into excess pore water pressures that superpose the changed hydrostatic pore water pressures. If the slope submerges into an open lake, a swift decline in the water table while the groundwater table remains the same is to be expected as a result of long waves that may be caused by the earthquake. The article shows how these forces generated by an earthquake are to be formulated and integrated into the static slice calculation of the usual slip circle method according to Bishop while retaining the static assumptions and simplifications of this method. Similar approaches were also developed for complex rupture mechanisms formed by several sliding bodies and straight slip lines.

References

[1] Prof. Klaus- G. Hinzen: Seismische Lasten für die Ermittlung von Böschungsstandsicherheiten (interner Bericht)
Design of underwater slope through the mining of sand and gravel — Strategies of avoiding failures

by Dr. rer. nat. Gernot Bode & Dr.-Ing. Volker Patzold
PÄTZOLD, KÖBKE & PARTNER ENGINEERS | Holm-Seppensen | Germany

With regard to several failures through the mining of sand and gravel, which have been investigated by the authors in the past and which caused significant damage of property, engineer office PÄTZOLD, KÖBKE & PARTNER ENGINEERS has developed efficient strategies to avoid them. These strategies are described below in general.

Introduction

The design of underwater slopes — as earth structures in the sense of DIN 4084 — through the mining of sand and gravel is often a cause of conflict between diverging interests of mining industry and supervisory authorities. On the one hand the mining industry is interested in the steepest slopes possible for economic reasons with the aim to maximize the recoverable and useable reserves. On the other hand supervisory authorities are interested in sufficiently stable and accordingly flat slopes for legal reasons.

For the stability analysis of underwater slopes in opencast pits there are at present no computational models but empirical results of investigations available as well as a specific planning system by BODE (2005) and PÄTZOLD et al. (2008) — as part of the planning system SAGALO — System zur Anlagenplanung für die Gewinnung und Aufbereitung von Lockergestein von PÄTZOLD, KÖBKE & PARTNER ENGINEERS (s. PÄTZOLD et al., 2004).

Applied praxis of dredging shows other long term stable underwater slope inclinations as expected according to usual calculation methods in DIN 4084. A consideration of dynamic loads due to different types of dredging as well as a consideration of dynamic processes on occasion of slope failures and turbidity currents is not possible by deploying earthstatic procedures or other available calculation methods — but these phenomenas are essential for the individual settlement of the underwater slopes.

A consideration of this circumstance can be evaluated as a first step in terms of the development of strategies of avoiding failures, which have led to significant damage of property in the past.

State of Technology

The state of technology in mining of sand and gravel in most of the opencast pits is currently characterized by a so called „uncontrolled“ dredging under water. This type of dredging can be executed with dredgers equipped with a controlled or uncontrolled loosening tool.

By deploying an uncontrolled dredging with a static positioning of the dredger and an uncontrolled execution of cuts slope failures are initiated, which affect the whole thickness of the dredged material and lead to so called „natural“ slope inclinations.

Material provided for extraction and dry material above the water level is permanently pushed into the water. As a consequence of these activities failures with a fallback behind the shoreline occur due to pull and erosion effects, as documented in figure 1.

The underwater slope is established by balancing of masses due to a relocation of the soil. In this context and with regard to time according to observations of the authors and by FRITZ (2001) fast and hurried ahead failures can be identified as well as slow and consecutively occurring failures. The design of complex slope systems with different slope inclinations is not possible nor designated in this context.

In general no controlling of the dredging process is established except of aligning and manual direction findings (s. PÄTZOLD & BODE, 2001).
This type of dredging, evaluated by MEYER & FRITZ (2001) as an „ungentle operating mode“ with regard to the stability of underwater slopes, is deployed in opencast pits with scope on production output only but taking into account significant mining losses (s. PATZOLD, 1994, 1995). With an increasing height of the slope the danger of uncontrolled failures with significant fallbacks behind the shoreline is maximized and therefore the extent of recovery is minimized – due to flatter slope inclinations of $\beta \ll \phi$ than established by dredging in a so called „controlled“ mode. Apart from that the danger of soil liquefaction is enhanced under accordingly endangered soil conditions. See figure 2 and figure 3 in this context.
By deploying uncontrolled dredging profoundly unstable slopes can be established with an inclination accordingly the critical angle of friction $\phi_c$ of the non cohesive soil. However, a contemplation of the slope stability according to DIN 4084 is not possible, as mentioned above, because resulting slope inclinations are obviously depending on dynamic processes on occasion of occurring slides.

Actually, while dredging in an uncontrolled manner and due to a permanent strain by dynamic loads on the underwater slope extremely flat slopes and disaggregations of the soil appear. In the s-shaped slope profile convex break offs due to slides in the upper part of the slope system and concave flattenings due to consecutively sedimentation in the lower part of the system can be identified. The upper part of the slope system stays in a metastable equilibrium. According to own echo soundings and corresponding observations by HORN (1969), BÖTTGER et al. (1978) and BÖTTGER (1983 a, b) gradual flattenings of the slopes can be observed in long terms – partially extending over several years.

In the course of an underwater slide a complete or extensive dissolution of the structure and structural capability of the non cohesive soil occurs. Therefore the slide corpus can not be recognized as a rigid body as in DIN 4084. On the occasion of turbidity currents a significant and grain size related separation and sorting in horizontal as well as in vertical direction occurs („avalanche effect“).

This can be proven by expansive clouds of suspended material and bubbles of soilgas in the water according to observations in various opencast pits by the authors. By mining companies a „boiling“ of the water is reported. For the lower part of the slope system a proximal sedimentation of coarse material and a distal sedimentation of fine material combined with a normal gradation and a slope averted cross-bedding has to be assumed.


The principle of uncontrolled dredging is shown in figure 4. The exemplarily pictured grab dredger is an example for all other dredger types by which a static positioned mining is executed as explained above.
An estimation of stable underwater slopes on occasion of uncontrolled dredging can be done according to PATZOLD & BODE (2004) and BODE (2005) on basis of results of a regression analysis with equation [1].

\[
H : L_{\text{eff}} = \left[ 5.260155 - 0.074211 \left( \frac{\phi}{\gamma_o} \right) + 0.004926 \cdot \mu_{\alpha} \right]^{-1/3}
\]

with:

- \( H : L_{\text{cr}} \) Ratio of inclination of the underwater slope [-]
- \( \phi \) Angle of friction of the soil [°]
- \( \gamma_o \) TPartial safety factor for angle of friction [-]
- \( \mu_{<0.63} \) Fine material with grain size diameter < 0.63 mm [% w/w]

Box-Cut Dredging

Under consideration of technical und commercial aspects and with regard to safety in mining sand and gravel there is no alternative method of dredging slopes than executing a so called „box-cut dredging“ underwater. This type of dredging, recommended by PATZOLD, KÖBKE & PARTNER ENGINEERS, can be executed with dredgers equipped with a controlled or – to a limited extent– with an uncontrolled loosening tool. From the procedural point of view the method of box-cut dredging is somewhere in between the so called „profile adjusted“ and the uncontrolled dredging. The principle of box-cut dredging is shown in figure 5.

In the course of mining several benches with limited height are established within the slope by cutting in steps from top downwards to the lower part of the slope system. Subsequently those steps fail in a more or less controlled manner. The height of the box-cuts has to be adapted to the local soil conditions. With regard to the soil-mechanical characteristics a lower box-cut height has to be chosen for fine to medium grained sand than for gravel, for example. The establishment of complex slope systems with varying slope inclinations is hardly possible by deploying the box-cut method. To distinguish between controlled and uncontrolled dredging a maximum box-cut height of $< 2.5$ m for fine to medium grained sand and of $< 5.0$ m for gravel has to be defined by the authors. The controlling of the dredging process is established by a continuous monitoring of the dredging progress and by an ongoing echosounding.

The deployment of this type of dredging is not limited to the field of hydraulic construction but comprises opencast pits („mine dredging“) with scope on minimization of mining losses. With a decreasing of the box-cut height the danger of uncontrolled failures of the slope is minimized accordingly. With an increasing of the slope inclinations, as a result of the deployment of the box-cut method, the degree of recovery is maximized correspondingly. Apart from that the danger of soil liquefaction is diminished compared with the application of an uncontrolled dredging.
Many experiences with good results have been made in this context in the administrative districts Cloppenburg and Leer, which have been notably affected by failures in the past because of specific endangered soil conditions.

Accordant experiences have been made since decades by mining brown coal in box-cuts (s. KARCHER, 2003).

By deploying box-cut dredging profoundly unstable slopes can be established with a grade of utilization of \( \mu = 1,0 \) and with an inclination between the peak angle of friction \( \phi_p \) and the critical angle of friction \( \phi_c \) of the non cohesive soil. This statement is limited to cases with no extra loads. For stability calculations of underwater slopes the critical angle of friction \( \phi_c \) has to be considered.

Actually, while dredging in a box-cut mode and due to a strain by dynamic loads on the underwater slope – which are not considered in DIN 4084 – failures can occur, which affect the whole thickness of the dredged material. In the slope profile, initially subdivided into steps and subsequently flattened, convex break offs due to slides in the upper part of the slope system and concave flattenings due to consecutively sedimentation in the lower part of the system can be identified, as well as on occasion of uncontrolled dredging. The upper part of the slope system stays in a metastable equilibrium – at least in single sections.

An example for the deployment of the box-cut mode is shown in figure 6, originated from an opencast pit in the administrative district Cloppenburg. The dredging data has been recorded by a dredge operation monitoring system make Arge VPC & SPE, type MARPO_DGPS_K. The figure illustrates the compliance of the dredging process (blue line) with the given profile (red line) as well as with the given box-cut height of 2,50 m according to official approval. This example shows a box-cut mode in an excellent workmanship, which reduces the risk of failures in the anent opencast pit significantly after having experienced some of them in the past.

The following principles have to be quoted with regard to box-cut dredging: Execution from top downwards to the lower part of the slope system and laminary, not stationary. A dredging process from the lower part of the slope system upwards to the top characterizes on the contrary an uncontrolled dredging with a serious threat of failure of slopes.

An estimation of stable underwater slopes on occasion of box-cut dredging can be done according to PATZOLD & BODE (2004) and BODE (2005) with equation [2].

\[
H : L_{\text{eff}} = \left[ \frac{1}{\mu_{\text{tab}} \cdot \alpha_{\text{dyn}} \cdot \tan \phi_c \cdot \gamma_{\phi}} \right]
\]

with:
- \( H_{\text{eff}} \): Ratio of inclination of the underwater slope [-]
- \( \mu_{\text{tab}} \): Grade of utilization under consideration of loads [-]
- \( \alpha_{\text{dyn}} \): Reduction coefficient for type of dredging [-]
- \( \phi_c \): Critical angle of friction of the soil [°]
- \( \gamma_{\phi} \): Partial safety factor for angle of friction [-]
Controlling Of Dredging Process

The development of strategies to avoid failures through the mining of sand and gravel is not possible without a controlling of the dredging process. For this purpose highly efficient systems are available at the market. Their deployment is the premise for the execution of the box-cut dredging and for the minimization of mining losses. As an example in this context the dredge operation monitoring system make Arge VPC & SPE, type MARPO_DGPS_K, has to be mentioned. The functionality of this system is described below:

- Configuration of the digital terrain model: Prior to installation of the system data of an exploration of the deposit, requirements according to official approval as boundaries of mining, slope inclinations and – if applicable – areas subject to a mining ban etc. as well as the geometry of construction of the dredger have to be prompted.

- Positioning of the dredger: The position of the dredger is determined via satellite-positioning. The position data is broadcasted by cable or radio and processed by the processing unit of the system.

- Positioning of the loosening tool: The depth of the loosening tool is determined by pressure cell, goniometer or echosounder. The position of the tool is identified via satellite under consideration of the geometry of construction of the dredger. The position data is broadcasted and processed by the processing unit of the system.

- Option for 360° sonar: For opencast pits with greater water depths there is an option for a 360° sonar by which mining field and slope area can be controlled continuously. The resulting slope configuration and sliding material are shown on the monitor of the system. The measured data is processed by the processing unit.

- Definition of water level: The changes of the water level can be prompted manually or by using a tide gauge.

- Visualization of mining: The dredging data is shown on a touch screen monitor in 2 image planes, as visualized in figure 7.

![Fig. 7: Dredge operation monitoring system make Arge VPC & SPE, type MARPO_DGPS_K.](image-url)
**Image plane I:** Map of area, position of the dredger, topography underwater, boundaries of mining, baseline of the slope and line of intersection for image plane II.

**Image plane II:** Crosssection, digital terrain model with position of the loosening tool as well as slope configuration according to official approval and according to progress of dredging.

The display of image plane II can be modified for a 3D-visualization of the area of mining and of the dredger. This option is also available for the visualization of the remaining thickness of sand, respectively gravel.

- **Analysis of the dredging data:** The dredging data, as position, time and dredging depth, is stored continuously on the system and is available for an analysis with the office software. Maps and cross sections as well as production and quantity calculations can be executed with this software.

**Concept Of Mining**

The preparation of a concept of mining and its implementation in the process of dredging is the key to avoid failures through the mining of sand and gravel. The basics in this context are described below:

- **Execution of a soil investigation:** For an evaluation of the stability of slope systems results of a soil investigation are necessary. That needs tables of strata, results of cone pressure tests, grain size distribution analyses and results of geophysical surveys for example.

- **Execution of an echosounding:** For an assessment of the stability of slope systems also results of an echosounding, respectively of a site survey, are necessary.

- **Execution of a slope stability analysis:** On basis of the results of the soil investigation and of the echosounding a slope stability analysis can be executed. That needs explicit knowledge about the soil conditions but also consideration of the dredging method.

- **Definition of areas subject to a mining ban:** On basis of a sensitivity analysis by comparing the configuration of the slope system according to official approval and according to progress of dredging the risk potential of neighboured estates has to be appraised. If applicable areas subject to a mining ban have to be defined. See figure 8 in this context.
The definition of areas subject to a mining ban is reasonable to minimize strain due to dredging in sectors affected by slope failures for example. The width of a bench in the sense of an area subject to a building ban according to Bundesfernstraßengesetz (§9, FstrG, 1994) and Niedersächsisches Straßenbandsengezetz (§24, NstrG, 1980) has to be defined in this case corresponding to the extension of concave flattenings due to consecutively sedimentation in the lower part of the system – in fact to protect the abutment of the slope. The extension of the bench can be derived under consideration of results of the slope stability analysis and of the echosounding:

- Preparation of a concept of dredging: On basis of the slope stability and sensitivity analysis as well as under consideration of the requirements according to official approval a concept of dredging has to be prepared, which is usually established as instruction manual.
- Preparation of a digital terrain model: By digitalization of the soil model as well as of the profile according to official approval and according to progress of dredging a digital terrain model has to be developed for the implementation within the dredge operation monitoring system make Arge VPC & SPE, type MARPO_DGPS_K.
- Installation of dredge operation monitoring system: Having prepared the digital terrain model the dredge operation monitoring system is ready for installation.
- Qualification of employees: For the qualification of the dredge master with regard to the operation of the dredge operation monitoring system and the execution of the box-cut dredging a training course has to be arranged.
- Analysis of dredging data: In context with maintenance works and functional tests of the dredge operation monitoring system an analysis of the dredging data within an interval of < 12 months is recommended. This analysis can be used as documentation of the dredging process in compliance with the requirements according to official approval.

**Summarizing** the above mentioned aspects and on the basis on the experiences of PATZOLD, KÖBKE & PARTNER ENGINEERS it has to be stated, that risks of failures through the mining of sand and gravel underwater can be minimized significantly by preparing and implementing a concept of mining, by executing box-cut dredging at the slopes and by using a dredge operation monitoring system. Apart from that, mining losses can be minimized by this procedure to a great extent.

**Literature**


Dr. rer. nat. Gernot Bode was born in Hanover in 1967. He graduated in geology and palaeontology at the university of Hanover in 1997 and was awarded with a PhD in 2005 at the same university after extra-occupational research work. After having finished his studies he worked in various engineering companies in the fields of mining, hydrogeology, geotechnics and environmental engineering. Dr. rer. nat. Gernot Bode is partner at Patzold, Köbbe & Partner Engineers since 2010.

Dr.-Ing. Volker Patzold was born in Hayingen / Lorraine in 1942. He graduated in mining at the technical university of Clausthal-Zellerfeld in 1968 and was awarded with a PhD in 1970 at the technical university of Hanover. After having finished his studies he worked in various companies in the fields of hydraulic construction and engineering, road construction and civil engineering. Dr.-Ing. Volker Patzold is proprietor of engineering office Dr.-Ing. Volker Patzold and senior partner at Patzold, Köbbe & Partner Engineers.

FOR MORE INFORMATION AND CONTACT:

Patzold, Köbbe & Partner Engineers
Partnerschaft
Dr. rer. nat Gernot Bode
Beratender Geowissenschaftler BDG
Dr.-Ing. Volker Patzold
Beratender Ingenieur VBI
Kleiberweg 20
21244 Buchholz i.d.N | Germany
Tel.: +49 (0) 41 87 - 312 - 306
Fax: +49 (0) 41 87 - 74 - 92
eMail: info@vp-engineers.de
Internet: www.vp-engineers.de
ContiTech Conveyor Belt Engineering – worldwide

There is just the right conveyor belt design for every material carried, every climate zone and every topography. ContiTech Conveyor Belt Engineering caters to this specificity with innovatively developed materials and production technology. **Keep on running.** High-end conveyor belt technology from ContiTech keeps conveyor belt systems running reliably and economically, with respect for the environment. Above and below ground, we offer a full range of equipment as well as comprehensive service, from installation through to start-up. Worldwide.

**ContiTech. Get more with elastic technology.**

ContiTech Conveyor Belt Group | Phone +49 5551 702-207
transportbandsysteme@cbg.contitech.de
Atlas Copco launches new and modified underground rock drills and stopers. The company introduces a range of silenced light rock drills for underground applications. A modified rock drill has passed the ATEX process and now fully complies to ATEX directive. Two versions of a new heavy-duty stoper are introduced.

Sound emission is an issue for surface and underground rock drilling. “Today customers more and more demand a silenced version of their rock drill”, explains Rikard Nordén, Product Line Manager Light Rock Drills at Atlas Copco Construction Tools. To meet the demand, a range of three silenced rock drills is launched. “The sound power levels of our BBC 16 WS, BBC 34 WS and BBC 94 WE have been reduced by 5-8 dB(A), depending on the model”, Nordén adds. “For the human ear this is perceived as a reduction of more than 50 %.”

Some technical modifications have contributed to achieve compliance with ATEX directive for the BBC 94 WS model together with BMK 91RS pusher leg. “Our only Atlas Copco light rock drill that has passed the whole process according to directive 94/9/EC,” explains Rikard Nordén. ATEX (ATmosphère EXplosible) directive consists of two EU directives describing what equipment and work conditions are allowed in an explosive atmosphere.

BBC 34 WS6 and BBC 34 WS8 are new heavy duty stopers which are added to the existing range. They are designed for tough working conditions in drilling, raise driving and bolting applications. They are suitable for medium to hard rock and benefit from a high impact energy blow and a strong rotation mechanism.

FOR MORE INFORMATION AND CONTACT:
Atlas Copco Construction Tools
Marketing Comunication/ Media Relations
Anja Kaulbach
Tel.: +49 (0)201 - 633 - 22 33
eMail: anja.kaulbach@de.atlascopco.com
Internet: www.atlascopco.com
Atlas Copco has elevated open pit mining to a new level with the launch of its latest down-the-hole drill rig – the SmartRig ROC D65s. This rig is the first of its kind in that it combines all the advantages of the well proven ROC L8 DTH drill rig with the advanced automation and control of the SmartRig family, thereby paving the way for new levels of productivity in surface drilling applications.

Atlas Copco has long and broad experience of its computerized Rig Control System (RCS) that forms the basis of the SmartRig platform. With the SmartRig ROC D65s, all the benefits of this system are now also available for open pit miners. RCS controls the entire handling of the drill rig, including everything from the drilling cycle to automatic tube handling and the optional hole navigation system. The system also facilitates the easy transfer of planning and performance data between the rig and the mine office.

The SmartRig ROC D65s is designed for drilling in the 110–203 mm hole range. It uses Secoroc COP 44, 54 or 64 down-the-hole hammers to a maximum depth of 54 metres. The drilling power is provided by an onboard Atlas Copco XRX10 compressor that supplies 30 bar pressure while a Caterpillar C15 engine, rated at 539 hp powers the rig.

Symbol of the future

“This is the future of small-hole drilling in open pit mining operations,” says Olav Kvist, Product Manager, Atlas Copco. “The capabilities of the ROC L8 and SmartRig have now been brought together in a single rig that offers a completely new drilling experience. One example is that the rig can automatically add and retract drill tubes, which relieves the operators of this tedious task so that they are free to prepare materials on the bench while the rig completes the hole by itself.”

The new SmartRig ROC D65s has been undergoing rigorous testing by mining contractor NCC Roads at the Aitik copper mine in northern Sweden where it has completed some 45 000 drillmetres in about six months. The results have been impressive, prompting NCC Roads to purchase this rig and an additional rig to be commissioned at the end of the year.
Advanced technology

NCC Roads has a fleet of 18 Atlas Copco rigs including SmartRig ROC D7C rigs for construction work. Martin Malmsten, Operations Manager says: “At NCC we always try to offer the most advanced technology available and that’s exactly what we are getting with this new SmartRig.”

“During the test period, we really came to appreciate the benefits of the RCS and automated systems which allow our operators to perform other important tasks around the site, while letting the rig do the drilling work by itself. This saves us a good deal of time and manpower.”

With three ROC L8 rigs in the fleet, in addition to ROC D7C and ROC D9C rigs, NCC’s operators are already well acquainted with the Atlas Copco Rig Control System, says Malmsten.

“Our operators are used to the Atlas Copco systems and they are positive to using the automated functions. They are very happy about getting the SmartRig because it makes their job easier – not only at Aitik but at many of the other sites where we are responsible for the drilling.”

With its first SmartRig ROC D65s in place, NCC is now able to move from test drilling operations to full production drilling using SmartRig technology at the Aitik mine. The second unit has been earmarked for commissioning later this year as production demands increase.

The open pit Aitik mine, located outside the town of Gällivare, is one of Europe’s largest copper mines and also produces substantial quantities of gold and silver. Annual ore production exceeds 18 million tonnes.

FOR MORE INFORMATION AND CONTACT:

Atlas Copco Surface Drilling Equipment
Vice President Marketing
Bo-Göran Johansson
Tel.: +46 (0)19 - 670 - 72 59
Fax: +46 (0)19 - 670 - 72 89
eMail: bo-goran.johansson@se.atlascopco.com
Internet: www.atlascopco.com

Atlas Copco Surface Drilling Equipment
Product Manager Automation
Olav Kvist
Tel.: +46 (0)19 - 670 - 74 22
Fax: +46 (0)19 - 670 - 72 51
eMail: olav.kvist@se.atlascopco.com
Internet: www.atlascopco.com

Atlas Copco Surface Drilling Equipment
Communications Professional
Marina Haikara
Tel.: +46 (0)19 - 670 - 74 35
Fax: +46 (0)19 - 670 - 72 51
eMail: marina.haikara@se.atlascopco.com
Internet: www.atlascopco.com

Atlas Copco Surface Drilling Equipment
is a division within Atlas Copco’s Construction and Mining Technique business area. It develops, manufactures, and markets rock drilling equipment for various applications in civil engineering, quarries and open pit mines worldwide. The division focuses strongly on innovative product design and aftermarket support systems, which give added customer value. The divisional headquarters and main production center is in Örebro, Sweden. More information is available on www.atlascopco.com.
As the geotechnical engineering market is growing, with new infrastructural projects, dams and construction in general, the need for ground investigation tools for those specific applications is also increasing. Atlas Copco has the products to meet these demands.

Terracore

Through the enhanced Terracore range of core drilling tools specially designed for geotechnical and soft rock investigation, the application and customer needs are addressed directly.

The range includes bits and In-The-Hole equipment for applications such as soft core sampling, ground investigation and foundation definition. The range is also suitable for other geotechnical applications, for example for drilling holes for grouting drainage, ventilation and pilot holes for raise boring.

Atlas Copco has been active in the core sampling field since 1886. Very early, the company was proven to be a great success and became synonymous with diamond core drilling equipment.

Atlas Copco has introduced many pioneering ideas to the diamond drilling industry, such as metric standard, automatic rod lifter, extra thin kerfs core barrels, the S Geobor core barrel, aluminium rods, impregnated bits etc. We will continue to keep this position by innovative product development, offering our customers cost efficient tools for profitable operations.

FOR MORE INFORMATION AND CONTACT:

Atlas Copco Geotechnical Drilling and Exploration
Vice President Geotechnical Engineering Business
Steve Greer
Tel.: +46 (0)708 - 56 - 96 14
eMail: steve.greer@se.atlascopco.com
Internet: www.atlascopco.com
Traditionally Wuppertal has set cultural and economical standards. The dancing theater Pina Bausch and Aspirin, both originated from here and had their effects well beyond the region. In 1901, when the elevated tramway started its operation, the great grandfather of the current managers Joerg Herrman and Moritz Iseke already celebrated the first anniversary of the establishment of Oetelshofen Kalk. Although the founder started his activities as a farmer in the Wuppertal-Hahnenfurth district in a manageable framework, the following generations further developed the family business – into a medium-sized company with currently 95 staff and an annual turnover of approximately 35 million Euros.

The program of the Wuppertalers includes mining of limestone and processed burnt lime products for diverse branches of industry. 75% of the products are being transported on road or rails within the radius of 80 km for the local economy. As an example, approximately 100,000 tons of powdered limestone is delivered annually by train for flue gas desulphurization plants of the Rhenish power plants.

The yearly production currently lies at 2 million tons. In order to sustain this for the future in an environmentally friendly way, Oetelshofen has invested – in the new firing technique of QualiCal, as well as in wear and noise protection of Sandvik. “The extraction of high-quality lime from the site is secured for the next 50 years. After that the engineers need to deal with mining under the ground water level.” Moritz Iseke explains.

“We have always been open to new techniques and technologies. Together with an Italian engineering office we have installed a new firing technology in a pilot project.

With an efficiency of 90%, the GGR- kiln (Counterflow-parallel flow-regenerative- construction) is attracting global attention. The innovative great grandson of the founder mentions enthusiastically “Almost every two weeks we guide an international delegation through our plant”.

Sandvik WT7000

Sandvik WT7000 reduces emissions by 20 DB and triples service life!
“In addition to our duty of care towards our staff, we naturally feel committed to nature and to the residents. This includes a reduction of noise emission,” Iseke complements the company’s philosophy. In this regard Sandvik was approached.

6 months before the company had already made first positive experiences with the Sandvik rubber wear plates WT7000, during the lining of an approximately 6m² funnel. The modular system is characterized by an easy installation and reduction of noise level by approximately 20 dB. The human ear perceives this as a reduction of noise emission.
by 50%. Convinced by this experience, the management decided to also equip the new 120m² collecting funnel with the WT7000 rubber plates.

The task was to select the right material for the requirements of the funnel, which is construed for approximately 500,000 tons of rocks per year. After a planning and consulting phase the decision was taken for 1,500 rubber plates with welding studs in a thickness of 50 mm, which meet the requirements of up to 60 tons of rocks per cavity, with a particle size of up to 140 mm.

In case the sharp-edged rocks should leave traces in the future, quick and economical remedy is available with an easy exchange of single plates with a weight of 5 kg each and a size of 300x300 mm.

“The basic element of the funnel is protected against cracks and deformations through the patented module plate system, therefore it stays in its original form, the special edge of the plates avoids the penetration of fine materials into the gaps. Furthermore the minimum threefold service time is an additional plus point. Selim Sahin explains: “These advantages cannot be offered by conventional solutions with metal and composite material. “

The 100% rubber plates have further advantages, like for example the easy cutting and the high environmental compatibility through recyclable material.

“The biggest population of owls can be found in the quarry, “ hunter Iseke says with pride. Every year three young animals hatch in the lime quarry Osterholz. Therefore the night hunters will be thankful to Sandvik for a two-shift operation and for the daily peace.

In the lime works, thought has already been given to future application possibilities of the Sandvik wear protection products, as well as on product and material testing on site. For example about the lining of the dumpers or the application of ceramics/rubber wear protection plates.

In the coming years the Oetelshofen company will continue to set standards, together with its business partners – compatible with nature and man.

FOR MORE INFORMATION AND CONTACT:

Sandvik Mining and Construction Central Europe GmbH
Sales Manager Wear Protection/Screening Media
Selim Sahin
Tel.: +49 (0)201 - 17 85 - 361
eMail: selim.sahin@sandvik.com
Internet: www.sandvik.com
Medium-sized enterprises like Herrmann Trollius Company in Lauterhofen are a main pillar of the minerals and soils industry. In order to remain competitive, while at the same time working economically sustainable, the operators observe high quality standards. In the production plants of the Lime and Schotterwerks Trollius both a well functioning system control, as well as meaningful process visualization play an important role. Through continuous investments in replacement and expansion, the machines and plants are up to date: Since August 2009 the recrushing of mineral concrete fractions is being done by a Metso ball crusher type Nordberg HP 100 modular.

Processing of limestone to mineral concrete and chippings is in the foreground in the Lauterhofen plant. Up to now the re-crushing to chippings was entirely done by an impact mill. With the increasing need for 2/5 and 5/8 fractions, the impact mill produced too much non-marketable sand 0/2. In order to produce a significantly higher amount of final grain – particularly 5/8- with considerably less sand, it was planned to crush a partial stream of the mineral concrete fractions 8/16, 16/22, 22/32 and 32/45 in a suitable crusher. Since the connection to the existing plant had to be simple and economical, the decision was made for a compact and mobile unit- without an own drive unit and undercarriage. Therefore, the pre-installed ballcrusher unit HP100 modular on a runner framework, which the Trollius company had already made out at the Steinexpo 2008, was taken into consideration.

This plant module could be set up and started in the shortest time. For connection the existing extractor at the respective silo chambers were activated. The regulated discharge for an even feeding of the crusher is done with frequency controlled vibrating feeders on a conveyor belt to the ball crusher. The output of the crusher reaches the elevating conveyor of the chippings screening plant via a connecting strip.

However, a high-performance ball crusher (HP is the abbreviation of high performance), like the HP100 is actually underchallenged from the technical point of view, even if it is dealing with high-quality, hard rocks at Trollius. Furthermore there is the danger of briquetting, particularly when crushing limestone with small gap widths. Herrman Trollius was not sure whether the grain shape would fulfill...
future requirements; therefore he first rented the modular unit for a trial operation. The HP100 was equipped with crushing tool standard medium, with which the throughput was 60 – 80 t/h at a gap width of 11 mm. A short time later the convincing results led to a decision in favor of the HP100 modular. The requirements regarding the final grain, low sand fraction and grain shape were met. The HP100, the smallest crusher of the HP series, provided the best pre-conditions for this operation, due to the convincing combination of crusher space profile.

Furthermore, service and maintenance-friendly characteristics like the accessibility of crushing tools from the top, as well as the fastening of the crushing tools without grouting material, play an important role in HP ball crushers of Metso. The efficient overload safety mechanism in unbreakable material or in the case of briquetting is also of advantage. The gap adjustment in HP ball crushers is done through turning of the chasing bearing, which leads to an even wear over the entire length of the crusher space.

For Trollius, the intelligent crusher control IC7000 Basic is sufficient to monitor the major crusher functions and to retrieve help functions in case of disruptions. In case an HP ball crusher is operated in highly abrasive rocks, the manufacturer recommends the IC7000 advanced, which, includes additional integrated functions for control of the system, as well as evaluation of the operation and several modes for monitoring the breaking gap for an operation with continuously optimal gap adjustment.

FOR MORE INFORMATION AND CONTACT:

At Trollius the Metso ball crusher HP100 is in operation for recrushing of limestone and dolomites.

Metso Minerals (Germany) GmbH
Herr Karl-Heinz Hessler
Obere Riedstr. 111-115
68309 Mannheim | Germany
Tel.: +49 (0)621 - 72 70 06 11
eMail: karl-heinz.hessler@metso.com
Internet: www.metso.com
Best results lead to the breakthrough

If crusher technology by Metso looks after anything, then it’s your purse: the Barmac vertical impact crusher protects the rotor which controls the process in an autogenous layer of feed material in crushing. The mobile Lokotrack LT1415 protects the nerves, as its large intake opening prevents bridging.

As a primary crusher, the LT140 saves time – in conjunction with the flexible Lokolink conveyor system it makes such progress in opencast quarrying that you can save a large proportion of your dumpers.

Talk to us about the possibilities of staying successful even in difficult times.

Metso Minerals (Deutschland) GmbH
Obere Riedstr. 111-115,
68309 Mannheim,
www.metso.com

Your contact person:
Karl-Heinz Hessler
Tel.: +49 (0)621 72700-611
Mobile: +49 (0)177 6608438
karl-heinz.hessler@metso.com
A new development from ContiTech minimizes rolling resistances and reduces energy consumption when transporting raw materials by 20%.

ContiTech presents new, energy-optimized conveyor belts. By developing a special rubber compound, the world’s leading manufacturer of conveyor belts has managed to minimize rolling resistance and so reduce energy consumption when transporting raw materials by 20%. This makes it possible to significantly decrease energy costs and CO2 emissions when conveying raw materials.

Given rising energy prices and a growing awareness of the need to protect the environment and climate, mining companies are increasingly focusing on cost and climate-friendly raw material extraction. Conveyor belt systems play an important role in this context because they use only a fraction of the energy that conventional means of transport do, and therefore emit significantly less CO2. In order to improve these excellent energy and environmental results even further, ContiTech is continuously researching and developing energy-optimized conveyor belts that will make operation of the systems even more efficient. The focus here is on reducing rolling resistances, because these have a major impact on the energy consumption of long, horizontal conveyor belt systems.

Cause and effect

At more than two thirds of the total, the rolling resistance accounts for the greatest share of movement resistance in a conveyor belt system. The cause: the viscoelastic material characteristics of the rubber conveyor belts. The rolling resistance is created, in part, by the movement over the idlers. In the contact surface between the conveyor belt and each individual idler, a force arises acting in the
opposite direction to the movement of the conveyor belt, resulting in additional energy consumption. In addition to a series of further factors, the rolling resistance depends on the technological properties of the conveyor belt and, more specifically, the material it is made of.

**Infinite possibilities – one ideal solution**

„The rubber compound plays a crucial role in the search for ideal material characteristics,” explains Wilhelm Schrand, head of research and development at the ContiTech Conveyor Belt Group. The many different ingredients and combination ratios result in infinite possibilities here. „Finding the right composition here is where ContiTech’s special skill lies,” says Wilhelm Schrand. „We can draw both on our decades of experience and on the interdisciplinary and very diversified knowledge of the large pool of experts in the company. At the same time, we keep in close contact with the system operators, making sure we’re well informed about our customers’ requirements so that we can take them into account.”

**Significant energy-saving potential**

Using complex simulations, ContiTech scientists adjusted the deformation of the conveyor belts over the idlers and derived hypotheses from this on how to provide the ideal rubber compound. On this basis, different compounds were mixed, tested and optimized, and the most promising compounds were turned into conveyor belts in order to try them out and find the ideal solution.

And it worked. The latest measurements, taken with special measuring devices on a test rig at the University of Hanover’s Institute for Transport and Automation Technology, showed significant reduction in rolling resistance with the newest energy-optimized conveyor belts from ContiTech. This resulted in an energy-saving potential of about 20%. A five km long conveyor belt system in an opencast lignite mine, for example, could save more than 3,000 kW of power. In an hour and a half, as much energy would be saved as the average four-person household in Germany consumes in a year.

**An ongoing issue**

„Although we’ve already achieved very good results, the issue of „energy-optimized conveyor belts’ will remain on our agenda,” explains Wilhelm Schrand. „We’re constantly working on improving our solutions even further, to play our part in ensuring that raw material conveyance becomes even more cost-efficient, environmentally-friendly and sustainable.”
BECKUM, 2010 – MODERN MINING TECHNOLOGIES REQUIRE BELT CONVEYING SYSTEMS THAT ARE CAPABLE OF MOVING INCREASINGLY LARGER VOLUMES ON GROWING CENTRE DISTANCES ACROSS IMPASSABLE AND MOUNTAINOUS TERRAIN, PARTICULARLY IN THE BRANCH OF COAL MINING. THE BEUMER GROUP, AN INTERNATIONALLY LEADING MANUFACTURER IN THE FIELD OF CONVEYING TECHNOLOGY, DEVELOPS AND Installs SUCH SYSTEMS.

TRANSPORT BULK MATERIAL WITH CURVED BELT CONVEYING SYSTEMS!

Companies require effective options for transporting bulk goods such as ore, coal, gravel or sand – for example from the mine, sand pit or quarry to the plant. Transportation by truck is expensive and has a negative impact on the environment. An economical alternative is a continuous conveyor, such as troughed or tubular belt conveyors. With the right design, these conveyors can be optimally adapted to the environmental conditions. Pollutants such as dust, noise emission and exhaust gases are minimised or even eliminated. By comparison to transportation by truck, large mass flows can be transported. Even in difficult environments, the construction work for these systems is minimal.

**Individual adaptation to the material**

The BEUMER Group designs and implements such conveying systems. The BEUMER belt conveyors are used as closed tubular belt conveyors or as open troughed belt conveyors. The BEUMER tubular belt conveyors are suited, for instance, for powdery material and on steep routes, the open troughed belt conveyors are used for robust or coarse material.

Due to their routing, the belt conveying systems negotiate rugged terrain and other obstacles, such as rivers, streets, buildings or train tracks. This reduces the costs of moving earth and expensive transfer points are significantly reduced. Horizontal and vertical curves can even overlap.

BEUMER offers the right solution for every challenge. Tubular belt conveyors are particularly suited to negotiate steep slopes or inclines and are suited for high quality or powdery materials. Inside the closed system, the material does not fall backwards and the excellent sealing allows the material to be transported dust-free. The BEUMER tubular belt conveyors are used for particularly tight curves, as they are able to better negotiate curves than troughed belt conveyors. The troughed belt conveyors transport larger volumes and mass flows and consume less energy.

BEUMER has already implemented belt conveying systems with centre distances of more than ten kilometres.
Focus on energy efficiency

The motors in these systems can be controlled, making optimal load distribution in the belt possible in all operating conditions. Depending on the terrain and loading condition, the systems can also operate as generators. The generated electric energy is fed to the mains by a BEUMER Maschinenfabrik GmbH & Co. KG regenerative feedback unit, helping to reduce energy costs for operating the whole system.

Made for a long service life

Belts on BEUMER systems reach long service lives of up to 20 years. The reason for this is the optimal design of the routes, drive technology, the take-up station and the arrangement of belt-guiding idlers. Exact calculations of the idler positions enable the belt conveyor to negotiate curves. If the system is designed optimally, an even stress on all components is ensured and the overall strain on the belt is minimised.

Consulting and design competence included

BEUMER engineers work with customers to design the static requirements for the bridges and belt conveying systems, optimise the route of the belt conveyor on-site and see the project through each phase of construction. Using their design competence, they make sure the investment and operating costs, as well as the required energy, is minimised.

BEUMER Maschinenfabrik GmbH & Co. KG
Oelder Str. 40
59269 Beckum | Germany

Distribution Conveying
Tel.: +49 (0)25 21 - 24 0
eMail: beumer@BEUMER.com
Internet: www.BEUMER.com

The BEUMER Group

As one of the international leaders in the manufacture of material handling systems for the conveying, loading, palletizing and packaging technologies, we know the routes your products take and their respective specific properties. With a workforce of almost 2,000, an annual turnover of EUR 375 million, is BEUMER including the own subsidiaries and holdings, as well as manufacturing facilities worldwide presented. More Information: www.BEUMER.com.
AT THE END OF FEBRUARY, KIESEL CELEBRATED THE OPENING OF ITS NEW BRANCH OFFICE WITH APPROXIMATELY 1,500 GUESTS ON A FESTIVE EVENING, FOLLOWED BY OPEN HOUSE DAYS. THE NEWLY ESTABLISHED SITE IS LOCATED DIRECTLY AT THE A2, AND IS THE SOUTHERNMOST OF THE SEVEN BRANCH OFFICES IN THE NORTHWESTERN SALES REGION OF KIESEL.

Growing Together

The new Kiesel branch office in Bielefeld is the first site to be inaugurated in 2010. Thus the Baienfurts do not only invest in expansion like almost no other construction machine business represented in Germany, but also in the depth of their service-oriented range of products. Kiesel is aiming at setting new regional standards with regards to costumer support with powerful branch offices.

This philosophy has also determined the establishment of Kiesel Berobau at the beginning of 2009. Through involvement of the Kiesel-Preissler locations, a high-performance sales region developed, which currently is for the lower Saxony and neighboring regions of Saxony Anhalt. Thus the regional subsidiary, which employs 130 staff, does not only take care of technically very different industry segments (e.g. sand/gravel/hard rocks), but at the same time it covers high density areas, as well as rural areas. Together with the two Kiesel main production lines Hitachi construction machines and Terex-Fuchs stakers, this ensures a broad composition of costumers.

All Kiesel sites are connected and equipped with the most modern IT-solutions for a smooth exchange of information. If required, the Kiesel team for product development supports the sales and marketing team with specialized knowledge on the industry sector and products, so that individual costumers are supplied with specialized solutions or specific system solutions for their respective sectors.

Furthermore, all Kiesel service packages like the group-wide leasing pool Kiesel PartnerRent (that also include special machines), as well as the centrally operating financing experts KieselFinance can be offered in the region.
Service to the Customer is a Big Issue

This widely IT-supported centralization of “informal” customer care – including the group-wide processing of orders – leads to the fact, that the overwhelming majority of the current 15 staff of the new Bielefeld site are directly working on customer service. The “front-team” comprises of 8 mechanics, one renting manager, as well as two sales and marketing experts. Four more staff organize the extensive own parts depot (approx. 5,000 items), the handling of service activities for the three product lines Hitachi, Terex-Fuchs and Kramer, as well as the cooperation with regional Kiesel partners for minor machines and stakers respectively.

“We really cover all construction machine areas in the region, from earthmoving to mine operations, the areas of demolition and recycling, up to extraction. Together with Terex-Fuchs we are leading in the areas of handling and disposal.” This is said by the new branch office manager Uwe Stratmann. “In this year we will be recruiting the first batch of trainees and train them in the group-wide training program, in collaboration with the vocational school in Breisach and the “Kiesel-academy”.

For this, one of the most modern operations in the Bielefeld area will be awaiting the trainees. 7,400 m² were built on a little less than 11.5 ha of own ground. All circulation areas are configured for burdens of up to 100 tons. A continuous hall height of 11.0 meters of the two working areas and the separate washing hall, as well as several heavy duty overhead cranes can even maintain the biggest construction machines or handling machines in Bielefeld, or can prepare them for delivery according to the customers’ wishes. “This has been an important prerequisite in planning and construction, particularly because we can use real advantage of location, especially in our main line Hitachi and its Dutch production plant.”, explains Uwe Stratmann and refers to customer-specific modifications, which can be carried out directly at the site, in close technical cooperation between the virtual axis Oosterhout-Baienfurt-Bielefeld.

Bielefeld à la carte

A good example of this strategy is the mobile excavator Hitachi ZX210W-3, which was submitted as one of the first “Bielefeld” new machines to the Bad Oeynhausener Kögel Bau GmbH & Co. KG.

Delivered ex factory with a 2.91-m shaft and boom, in Bielefeld the 22 ton wheel excavator received a broadened...
undercarriage (2750 mm) with Caliber-twin tyres and an Oilquick-quick changer OQ 70/55. As digging tools, Kiesel delivered a hydraulically adjustable 2.0 digging bucket, as well as special 800 mm- and 1,200 mm trench buckets with elongated blades, respectively. A piping for hammer and cutter applications, a central lubrication (Beka-Max), as well as additional rear reflectors complete the extras of the Hitachi serial equipment components, which is already extensive (rear camera, satellite remote monitoring, etc.), in the striking red of Koegel. Here safety is a big issue: The optionally built-in side camera and an additional LCD monitor provides the driver with a free view over the entire right area of the machine. Hereby a state-of-the-art fleet is a prerequisite, but no burden: For a fairly long time Koegel has “outsourced” maintenance and service of its machines, which are designed for four to five years in operation, to respective subcontractors. For short-term provision of additional capacities it also relies on habitual partners. Good prospects for Kiesel Bergbau, with its close-meshed service network in the direct catchment area of Koegel and its full interlocking in the nationwide Kiesel-drive.

The Bad Oeynhausen KÖGEL Group, with the three enterprises „KÖGEL Bau (construction), Bausanierung (reconstruction) und Rohrtec“ has developed into an important nationwide construction partner, which effectively sets standards.

Since its establishment as a construction operation in 1965, the enterprise has consistently followed only one goal: To noticeably improve the quality of life, work and living of clients in all questions related to construction: collectively – safely- strongly.

The enterprise, which meanwhile is three-membered, has expanded its core competences, i.e. construction above and below ground and road construction, by conservation and reconstruction, as well as ready-to-use industrial and commercial buildings. Since 2003 the group owns the company Rohrtech and thus it holds authorization for laying gas and waterpipes. Among others, these competences are complemented through landscaping and extensive services.

A future and growth-oriented economic action and a responsible handling of all resources has made it possible to offer regional and supra-regional customer support, and has ensured 130 jobs and training positions in the region. Qualified skilled workers with a broad innovative, technical know-how, a modern high-performance machinery, systematic quality management and forward-looking computer and communication technology ensure chronologically and economically optimized project progress.

In order to ensure this for both the present and the future, the KÖGEL group places great emphasis on training and in-service training of staff. Motivation, leadership, technical competence, perspective -- this is the KÖGEL agenda. Regular further education and trainings ensure the high quality standard of our enterprise.

FOR MORE INFORMATION AND CONTACT:

Kiesel GmbH
Baindter Strasse 29
88255 Baienfurt | Germany
Tel.: +49 (0)751 - 500 40
Fax: +49 (0)751 - 50 04 88
Internet: www.kiesel.net

Kiesel GmbH
Alexandra Schweiker
Tel.: +49 (0)751 - 50 04 45
Fax: +49 (0)751 - 50 04 50
eMail: a.schweiker@kiesel.net
Internet: www.kiesel.net
Kawasaki wheel loaders are known for their reliability and long life. The box frame, low hinged lift cylinders and two bucket cylinders make these vehicles even more robust. Peter Stuijt says: “The introduction of the ZW330, ZW370 and ZW550 is a good example of what can be achieved through exchange of information and technology. We are sure that the new models will be well received by our growing customer base in this area”.

**Higher Performance**

The ZW330, ZW370 and ZW550 are equipped with powerful and economical motors, which can operate in two different operation modes: either in power- or in fuel saving modus. These operation modes can be chosen according to demand and increase productivity and efficiency.

The large models of the ZW series are serially equipped with standard torque proportioning differentials (TPD), which controls the distribution of torque to the wheels. Optionally axles with Limited Slip Differential (LSD) are also available. Furthermore the two models ZW370 und ZW550 are equipped with a traction control, which adjusts the engine rpm automatically to the working conditions.

The load-sensing hydraulic steering system boosts steering force, when needed, in the main hydraulic circuit. This makes the full use of pump torque possible for higher job efficiency. The ZW370 and the ZW550 are equipped with a torque convertor for improvement of the overall performance.

**Comfort and Safety**

The spacious cabin, which complies with the ROPS/ FOPS safety regulations, rests on viscous mounting to absorb vibrations during the operation. The fully adjustable air suspension seat also contributes to the creation of a comfortable working environment for the driver. The vibration absorption ensures a smooth operation and automatically adjusts itself to soil conditions.
The wet disc parking brakes ensure an extraordinarily good braking force. The dual circuit brake system, with which Dual lines are independently provided for front and rear axles, are an additional safety feature. The lock-up clutch in the torque (coupling release point) can also be adapted to local conditions, for example for an efficient operation on level terrain and excellent performance on hills.

The adjustable steering column, automatic climate control, automatic lift arm control, the directional switch and the kick-down knob serially increase driver’s comfort.

**Lower Operation costs**

The models ZW330, ZW370 and ZW550 have a set of performance characteristics, which lead to a decrease in fuel consumption and the overall operating costs. The computer-based engine control module (ECM) provides essential operating data for quick fault diagnosis and troubleshooting. Further diagnosis tools also provide key engine data for accurate analysis, which reduce downtime.

The speed of the highly developed hydraulic cooling fan speed varies with changes in operating temperatures, which leads to reduction in noise and fuel consumption. The automatic reversible fan can be swung open manually for easy cleaning of radiators.

The idle management system keeps engine speed low during long-time breaks, thus leading to fuel saving. This system also increases engine speed for quick warming-up of the motor in cold weather. The Efficient Loading System (ELS) increases traction force during loading and grants higher productivity while at the same time reducing fuel consumption.

Due to an optimum penetration behavior, the durable buckets reduce fuel consumption. The bucket hinge pins are sealed to retain grease inside. This gives them longer service life and minimizes downtime. Thanks to the usage of components that are manufactured in-house, like for example the power-shift gear, the axles and the hydraulic, the vehicles are operational, even under the most difficult working conditions.
All important parts of maintenance are easily accessible; therefore inspection work can be done easily and quickly. Filters and grease fittings are grouped for the convenience of replacement and lubrication. Furthermore the machines are coated with Hitachi’s advanced multi-coat painting process, which is not only highly robust, but also very resistant to corrosion and mechanical damage.

<table>
<thead>
<tr>
<th>Specifications</th>
<th>ZW330</th>
<th>ZW370</th>
<th>ZW550</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum engine power (kW) ISO 9249</td>
<td>242 (325 PS)</td>
<td>268 (359 PS)</td>
<td>360 (483 PS)</td>
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<tr>
<td>Operating weight (kg) *</td>
<td>26.500</td>
<td>31.400</td>
<td>48.200</td>
</tr>
<tr>
<td>Bucket capacity (m³)</td>
<td>4,6 – 5,2</td>
<td>4,9 – 5,8</td>
<td>6,2 – 6,9</td>
</tr>
</tbody>
</table>

* for standard configuration

**FOR MORE INFORMATION AND CONTACT:**

**Kiesel GmbH**  
Baindter Strasse 29  
88255 Baienfurt | Germany  
Tel.: +49 (0)751 - 500 40  
Fax: +49 (0)751 - 500 48 88  
Internet: www.kiesel.net

**Kiesel GmbH**  
Alexandra Schweiker  
Tel.: +49 (0)751 - 50 04 45  
Fax: +49 (0)751 - 50 04 50  
eMail: a.schweiker@kiesel.net  
Internet: www.kiesel.net
CAT® 988H UPDATE DELIVERS MORE VALUE FOR CUSTOMERS THROUGH IMPROVED SYSTEMS, LOWER COSTS AND OPERATOR WELL-BEING

Building on this 988 legacy, Caterpillar has now introduced an updated 988H, which blends the best of its predecessor’s qualities with up to 10 percent greater fuel-efficiency and new features that boost production, lower costs, enhance the operator’s environment and further advance the 988’s legendary durability and reliability. The refined design of the latest 988H, combined with the strength of the Cat dealer network, provides uncommon value for the customer.

Updates

Included in the updated 988H package is the new Positive Flow Control (PFC) implement hydraulic system, designed to boost loading performance and save fuel. Complementing the PFC system are redesigned buckets, which load easier and increase fill factors, plus loader-linkage changes that add breakout power.

Modifications in the braking system improve retarding capabilities and extend brake life, while new fuel-management features increase fuel-saving potential. To further refine loading efficiency, the optional Payload Control System has increased accuracy, is more robust in design and easier to calibrate.

For the operator’s comfort, convenience and safety, cab sound levels are significantly reduced and a new electro-hydraulic implement pod reduces operator effort and fatigue. Hinged mirrors allow safer access for windshield cleaning, and an optional heated seat and new radio options (Bluetooth, Auxiliary, MP3 and Satellite) mean greater operator comfort.

Loading power and fuel-efficiency

The Positive Flow Control hydraulic system uses a new electronically managed, variable-displacement pump that works with an integrated solenoid valve with force feedback to precisely manage oil flow. The PFC system assures that pump displacement is always precisely matched to loading conditions. The system regulates oil flow in proportion to lever stroke, improving hydraulic response and creating an overall hydraulic efficiency that results in less heat and decreased fuel use.
A 5,000-psi (34 500-kPa) pressure boost in the boom-lift circuit increases bucket-breakout force, and a regeneration valve on the linkage assures positive cylinder response. The 988H update also offers a new Performance Series bucket line that retains material more effectively and provides increased fill factors (volume loaded, versus rated capacity). The buckets have a wider throat, longer floor and improved setback angle.

The 988H update highlights three programmable fuel-saving features: the Fuel Management System (FMS); Auto Idle Kickdown (AIK); and Idle Shutdown.

The FMS, which has been standard on the 988H since June 2007, allows customers to set machine parameters to match production demands. This is accomplished through three modes of operation—Full Power mode (FMS not engaged), Balanced mode and Maximum Fuel Saving mode. By choosing either the Balanced or Maximum Fuel Saving mode, the operator can set the machine to automatically reduce engine speed and hydraulic flow when the 988H is outside its dig segment, adding to potential fuel savings by up to 15 percent.

New for the 988H update is the AIK feature. If the 988H is not being actively operated for a period of time, the AIK system will temporarily reduce engine speed to save fuel. The system automatically resumes engine speed to the previous setting when the operator engages the implement control pod or the F-N-R switch or the STIC Steer. The Idle Shutdown feature, also new for the 988H update, automatically shuts down the engine after the machine has been in a safe idling state for an extended time. The operator receives an in-cab audible/visual warning before the engine shuts down.

The optional Payload Control System (PCS) 3.0 is a new on-the-go weighing system that helps the 988H operator fill each truck with an accurate payload—typically to within ±1 percent. The new system requires calibration only once per year and provides a simpler interface and an intuitive graphic display. PCS 3.0 can record details—material, date, time, number of passes and ticket number—for up to 1,000 truckloads and can identify up to 50 trucks.

Safety and operator amenities

In the cab of the new 988H, laminated glass is used in the rear window and both rear side windows. The laminated windows have two panes of glass separated by an air gap, which dampens window vibration caused by external noise sources, such as the engine and hydraulic pumps. The new windows complement a laminated windshield and laminated front side windows to reduce interior sound levels by a significant 1 dB(A), to 72 dB(A).

Loader controls for the 988H update are positioned in a new, low-effort, electro-hydraulic implement pod that features fingertip levers that improve both control and ergonomics for the operator. The new control levers also use “soft detents,” which replace conventional detent magnets with electronic sensors that provide easier lever control.

New operator-environment features build on traditional 988 safety features, including superior visibility (large glass areas, long-life LED lights, and optional rear-view camera); access and egress precautions (lighted primary/secondary stairwells, full-perimeter railings); maintenance provisions (ground-level/platform access, electrical-disconnect switch); and operator comfort and well-being (adjustable controls, air conditioning, optional ride-control, secondary steering system).
Solid foundations

The 988H update retains all the solid characteristics that have established the 988’s reputation for durable, reliable, efficient performance. The new machine’s massive box-section rear frame and box-shaped loader tower are designed to resist operating forces, and both use castings in critical areas of high stress. The distinctive fabricated box-boom has more torsional stiffness than boom arms used in conventional Z-bar linkages, and the boom works smoothly with dual bucket links to provide superior breakout forces and durable performance.

The power train likewise incorporates established 988H technology, including the Cat ACERT™ C18 engine with electronically controlled fuel injection and Next Generation Modular Radiator with 14 parallel-flow circuits for optimum cooling. The field-proven power shift transmission uses the Cat Impeller Clutch Torque Converter and Rimpull Control System to balance hydraulic power with tractive effort, and massive Cat built axles feature planetary-reduction final drives positioned at the wheel ends to reduce axle-shaft torque loads.

As proof of its outstanding ability to assure customer value, the newest 988H, as with its long line of predecessor models, has the design integrity to yield a life of productive service, then can be economically rebuilt to yield exceptionally low lifetime operating costs.

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Basic 988H Update Specifications

<table>
<thead>
<tr>
<th>Specifications</th>
<th>988H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>Cat C18 ACERT</td>
</tr>
<tr>
<td>Power (gross)</td>
<td>555 HP (441 kW)</td>
</tr>
<tr>
<td>Operating Weight</td>
<td>110.549 lb (50.144 kg)</td>
</tr>
<tr>
<td>Rated Payload</td>
<td>12.5 tn sh. (11.4 t)</td>
</tr>
<tr>
<td>Bucket Capacity Range</td>
<td>8.2-10 yd (6.3-7.6 m³)</td>
</tr>
<tr>
<td>Hydraulic Flow</td>
<td>130 US-Gall/min. (492 l/min)</td>
</tr>
<tr>
<td>Relief Pressure</td>
<td>5075 psi (35.000 kPa)</td>
</tr>
</tbody>
</table>

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FOR MORE INFORMATION AND CONTACT:

Press Inquiries Europe, Africa and Middle East
Mia Karlsson
Tel.: +41 (0) 22 849 46 62
Fax: +41 (0) 22 849 99 93
eMail: Karlsson_Mia@cat.com
Internet: www.cat.com

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Caterpillar
For more than 80 years, Caterpillar Inc. has been building the world’s infrastructure and, in partnership with its worldwide dealer network, is driving positive and sustainable change on every continent. With 2009 sales and revenues of $32.396 billion, Caterpillar is a technology leader and the world’s leading manufacturer of construction and mining equipment, diesel and natural gas engines and industrial gas turbines. More information is available at www.cat.com
Liebherr has commissioned their new flagship R 9800 mining excavator to be operated by Thiess Pty Ltd at Peabody’s Burton Coal Project in Central Queensland, Australia.

Liebherr’s experience over many years in designing, manufacturing and servicing large hydraulic mining excavators has been applied in the complete new development of this 800 metric tons ultra class excavator. The development was conducted in a close relationship with Thiess personnel based in Australia. This first unit commissioned in the field and working at Burton Mine is the largest backhoe excavator in the world.

The first face shovel unit version of the Liebherr R 9800 is currently undergoing Liebherr’s intensive factory testing prior to first field operations.

The outstanding production performance of the R 9800 is achieved by applying latest technologies together with Liebherr’s experience to the overall power train, hydraulic system with controls and new engineering approaches in all the major steel structures. These new approaches allow on the R 9800 a nominal bucket capacity of 42 m³ as a backhoe and 42.7 m³ as a face shovel. The first trials with Thiess at Burton Mine show that the machine achieves cycle times down to below 29 seconds and bucket payloads with 75 metric tons per pass.

The R 9800 is operating with a 45 m³ high production volume bucket specifically designed to suit the overburden conditions at Burton. With this bucket the machine achieves a 3-pass loading of 220-metric-tons class dump trucks.

The R 9800 at Burton Mine is powered by two 1,492 kW / 2,000 hp Cummins QSK 60 diesel engines in TIER 2 configuration. Further tests on a fuel optimized engine setting are already scheduled. A MTU powered version and an electric version will be available in the future.

The break-out and digging forces are optimized for a best possible penetration. The R 9800 provides the highest specific digging forces in the ultra class excavator range. The high digging forces combined with the large hydraulic performance form the basis for an optimum bucket fill factor at low cycle times.
Strong focus in the development has been the overall machine efficiency. Reducing the power consumption of auxiliary systems, increasing hydraulic piping and hose diameters and operating at the highest pressure level in its class make the R 9800 the most efficient hydraulic mining excavator ever built.

Operators and Service crews find on the R 9800 an out-standing working environment with latest ergonomic and safety principles applied in the machine design. The spacious and super silent cab, with its large front windshield, offers an excellent all-around view of the working area.

Providing more uptime, the R 9800’s conception is focused on ergonomic, safe and comfortable serviceability, offering easy inspection access and short maintenance times. All service fluids can easily and quickly be exchanged or refilled through the service flap. Combined with extended service intervals of up to 1.000 SMU, Liebherr’s R 9800 is the basis for maximum production hours.

FOR MORE INFORMATION AND CONTACT:

Liebherr-France SAS
Swann Blaise
B.P. 90287
68005 Colmar/Cedex | France
Tel.: +33 (0) 389 - 21 - 39 33
Fax: +33 (0) 389 - 21 - 38 00
eMail: swann.Blaise@Liebherr.com
Internet: www.Liebherr.com
In March 2010, TAKRAF GmbH, a subsidiary of an Italian company, Tenova S.p.A., signed a cooperation agreement with Liebherr Werk Biberach GmbH, for the development of a new diesel-electric drive system for TAKRAF surface miners.

Tenova TAKRAF, a leading supplier of continuous mining equipment is extending its product range with the new Tenova TAKRAF Surface Miner TSM 500 for the extraction of soft to semi-hard material with the new energy saving diesel-electric drive system.

Typical for the Tenova TAKRAF surface miner is the unique cutting drum arrangement located ahead of the machine. This ensures that the crawlers always move on a plain, newly cut surface. This minimizes the load on the crawler track components and substantially improves operational stability of the machine.

Compared to other products, the TSM’s cutting drums are considerably larger in diameter. The TSM 300, a medium size machine, reaches a cutting depth of 800 mm. The resulting large cutting cross section permits a considerable slower travelling speed and low cutting drum rotational speed. This reduces crawler track wear and cutting tool consumption, which results in more favourable operating costs compared to other supplier’s equipment.

The Tenova TAKRAF front drum technology, in particular the “top down cutting direction, has process advantages. The product generated by the TSM is characterized by a narrow and steep material distribution curve, eliminating the need for certain crusher process steps, and minimizing material transfers, compared to other means of transportation (e.g. trucks or mobile bridges).

For some time now Tenova TAKRAF Surface miners are equipped with frequency-controlled high efficiency conveyor drives. Based on Tenova TAKRAF’s decade long experience with the supply of electrically operated mining equipment, Tenova TAKRAF explored the possible integration of an innovative electrical drive system completely enclosed in the cutting drum. This resulted in a patented solution and the project for the new TSM500e high performance Surface Miner.

For the realization of the project, Tenova TAKRAF found an excellent partner in Liebherr Werk Biberach GmbH, who has many years of experience in the field of diesel-electrical drive systems.

The TSM 500e will be equipped with a 2x500kW cutting drum drive. The drive-modules, comprising planetary gears and integrated electrical motors, feature an extreme compact design. This allows integration into the cutting drum similarly to the proven technology of the wheel drives.
in large mining trucks. In addition to the cutting drum drive, the undercarriage travel drives and all other drives will also be powered by electrical motors.

The intelligent control of the TSM500e ensures a considerable increase in fuel efficiency, especially in partially loaded operating conditions. Compared to similar surface miners with diesel-hydraulic drive systems, the TSM500e’s diesel fuel consumption will be reduced by more than 100,000 l per year. The TSM500e’s diesel engine already meets EU2 and USA Tier II emission standards, reducing operational costs and CO2 emission.

The TSM500e has a design capacity of 2,400 m³/h and achieves a cutting depth of 1.1 m. The machine will be equipped with all safety, maintenance and operational features currently included with the TSM300. This includes amongst others a spacious and air-conditioned operator’s cab. The cabin is soundproof and conforms to ROPS/FOPS-protection standards. The heavy duty 230V on-board train power system with HID operation lights facilitates an optimum illumination of the surroundings. Also included are a central lubrication system, an automatic fire extinguishing system in the engine compartment and a service station near ground level. The operation of the TSM500e will be enhanced by a machine diagnostic system, integrated inclination-adjustment and cutting depth control.

The new TSM500e provides an unique combination of a highly efficient, cost effective, low emission and heavy duty miner.
Tenova TAKRAF presents a new generation of fully mobile crushing systems for open cast mining operations!

Tenova TAKRAF presents the TAKRAF Mobile Crushing Systems—TMCS® a series of newly developed mobile crushing plants as a modular system for a capacity range from 3,000 to 12,000 t/h. The versatile system serves as a flexible link between mining shovel and face conveyor. The expensive fleet of haul trucks therefore will be largely eliminated.

Tenova TAKRAF presents the TAKRAF Mobile Crushing Systems—TMCS® a series of newly developed mobile crushing plants as a modular system for a capacity range from 3,000 to 12,000 t/h. The versatile system serves as a flexible link between mining shovel and face conveyor. The expensive fleet of haul trucks therefore will be largely eliminated. The TMCS® may be combined with a belt wagon or a mobile conveyor bridge which are capable of spanning up to 3 benches of 15 m height or more from one face conveyor. In a single bench operation the TMCS® can also work without any additional mobile link conveyors. The mobile crusher is extremely manoeuvrable catering for continuous and synchronous movement with the face shovel. The fixed and oversized discharge conveyor below the crushing unit equalizes material flow and minimizes spillage.

The TMCS® concept allows the arrangement of travel crawlers close to head and tail extremities of the rigid superstructure, e.g. supporting the receiving hopper that is located right above a pair of equalized crawlers. Via those crawlers the high impact loads are directly transferred into the ground. A ball point provided atop the two-crawler undercarriage below the crusher allows rotation around the vertical axis for steering purposes. Hydraulic steering cylinders, as well as auxiliary hydraulic supports are not required anymore. The ability to relocate the whole system without interrupting the material flow is the main innovation of the new generation of the TMCS® fully mobile crushing plants. Thus, the ability to constantly move the TMCS® saves valuable operating time and improves the availability and utilization of the entire mining system.

The TMCS® can either be equipped with a double roll crushe or a twin shaft sizer. For maintenance purposes there sufficient space is provided ahead of the crushing unit itself, to move it out towards the head of the crusher discharge conveyor.

The TMCS® series has been designed to work in conjunction with the standard shovel range of 20 to 65 cubic meters. Due to the modular system the TMCS® can be adapted to your mine requirements.

FOR MORE INFORMATION AND CONTACT:

Tenova TAKRAF
Torgauer Straße 336
04347 Leipzig | Germany
Tel.: +49 (0) 341 - 24 23 500
Fax: +49 (0) 341 - 24 23 510
eMail: sales@takraf.com
Internet: www.takraf.com
www.tenovagroup.com

Tenova TAKRAF
Bahnhofstraße 26
01979 Lauchhammer | Germany
Tel.: +49 (0) 3574 - 854 0
Fax: +49 (0) 3574 - 854 100
eMail: service@takraf.com
Internet: www.takraf.com
www.tenovagroup.com
NEW GENERATION OF KLEEMANN IMPACT CRUSHERS PUT TO THE TEST!

Series production of the new MR 110 EVO and MR 130 EVO starts with several months of extensive testing and various prototypes successfully behind it.

The proof of the pudding is in the eating, as they say. And the question on everybody’s lips for a brand new design is whether or not its practical use will confirm that which was developed in theory. After approximately one and a half years under development, the first prototype was put to the test in late summer of 2009. And initial results have already impressively shown that the entire concept is spot-on. Right from the very start, the smaller of the two plants, the MR 110 EVO, was able to achieve a maximum feed capacity of 350 t/h without a problem.

Initial tests confirm that extremely high continuous output is possible

The first tests were carried out at a recycling centre located near to Kleemann’s headquarters in Göppingen, Germany. The charged material was made up of mixed demolished concrete from demolition waste, initially containing relatively low amounts of ferrous material. Feed sizes generally remained below 600 mm. When they occasionally exceeded this, however, not once did it pose a problem for the adjustable, remote-controlled cover at the crusher inlet. The most varied of materials were experimented with over the course of the first test phase, which often included demolition waste containing high levels of ferrous material to push the technology to its limit. The results were very promising: The plant was able to maintain the high performance values even at continuous output. It soon became apparent that, thanks to the new material flow concept, wear and tear at important points such as rotor ledges or the discharge conveyor belt could be considerably reduced. And, of course, any additional problems that emerged were also recognised and successfully rectified.

It was important for the plants to be tested by different customers or operators in order to gather a varied selection of feedback for the new operating concept. This also guaranteed that a wide range of charged material was crushed during the test phases.
Cold testing conditions at times

One of the test stations was a company in the Allgäu region in Southern Germany. Here, the plant was again put through its paces for the most varied of applications and, thanks to a fairly severe winter with temperatures reaching as low as -23 degrees, also tested under genuinely cold conditions. First, there were several thousand tons of gravel broken, then slabs of asphalt were processed, followed by reinforced concrete with larger and smaller pollution ratios. Feed capacities of 350 t/h were consistently achieved over longer periods of time and were even occasionally exceeded.

The larger plant from the new series, the MR 130 EVO, was also comprehensively tested. As operation of this prototype took place some time later, the experience gained from testing the MR 110 could be implemented and any „teething problems“ avoided from the outset. And here, too, the potential of these machines was immediately apparent. A maximum feed capacity of 450 t/h was quickly realised and, at times, considerably exceeded. During the first test, for example, the MR 130 prototype proved to be significantly faster in asphalt recycling than originally planned.

Test conclusion:
The concept works! Enormous capability with significantly greater economic efficiency

These extensive testing procedures, which included all possible plant applications in use today (in one case even slag was processed), confirmed what had been proven in theory. The two plants are both cost-effective and resistant to wear; the new material concept not only effectively allows for better performance but also increased durability. Longer service life, together with an extremely efficient direct drive, lead to noticeable savings in operation costs. All in all, a major success for Kleemann.
The world market leader in cold milling machines launches the new Vacuum Cutting System suitable for use in front-loading road milling machines. VCS reduces the amount of airborne material particles which are produced by the milling process. Wirtgen GmbH is the only manufacturer worldwide to offer a Vacuum Cutting System for cold milling machines.

VCS in detail

The VCS – VCS being short for Vacuum Cutting System – works according to the following principle: fine material particles and water vapour are created inside the milling drum assembly during the milling process. VCS applies negative pressure to suck these fine particles into the milling machine’s short conveyor channel. Additional sealing of the milling drum assembly supports this process. A suction hood located above the conveyor channel sucks the particles into two hoses which transport the extracted material particles directly to the long conveyor of the loading system, thus avoiding the point of transfer of the milled material from the short to the long conveyor. Here again, the process is supported by sealings in the short conveyor channel and at the suction hood. A hydraulically driven centrifugal fan installed on the conveyor additionally ensures that the extracted material is fed into the long conveyor channel. Negative pressure is created in the milling drum assembly at the same time. Additional injection of water at this point binds most of the particles.

The water-bound particles are finally returned into the stream of material and are, for the most part, fed into the truck together with the milled material during the loading process.

Ideal working conditions for the machine operator

Benefits for the machine operator resulting from the immediate extraction of particles include a perfect view of the milling edge. VCS provides significantly improved visibility in particular when cold milling machines are in operation at night. Yet another advantage resulting from the use of the optional VCS in cold milling machines is the distinctly reduced level of contamination of the engine by the fine particles created during milling. Reduced contamination, in turn, benefits machine users and maintenance staff when it comes to replacing diesel, air and oil filters. In the long term, this will result in corresponding
cost savings. VCS offers additional positive effects in that in particular those parts of the cold milling machine generally remain cleaner which are especially prone to the adverse impact of the fine material particles, such as the greased lifting column guides. The W 100 F, W 120 F and W 130 F small milling machines, as well as the W 150, W 200, W 210, W 2100 and W 2200 large milling machines are suitable for use with the vacuum cutting system.

Positive results in test series

Wirtgen has made the machine operator and his workplace the centre of its engineering and development work for many years. Current issues related to safety at work, such as the discussion on the adverse effects of fine particles on the machine operator, are followed in the construction equipment industry with great interest. Technical innovations like the vacuum cutting system, which is a result of Wirtgen GmbH addressing this issue in the most thorough fashion, make a contribution towards reducing any potential health risks.

An independent testing laboratory has performed extensive test series on Wirtgen cold milling machines equipped with the Vacuum Cutting System – with successful results: the VCS technology is recommended by the Employer’s Liability Insurance Associations on the basis of these tests.

FOR MORE INFORMATION AND CONTACT:

Wirtgen GmbH
Claudia Fernus
Reinhard-Wirtgen-Straße 2
53578 Windhagen | Germany
Tel.: +49 (0)26 45 - 13 17 44
Fax: +49 (0)26 45 - 13 14 99
eMail: claudia.fernus@wirtgen.de
Internet: www.wirtgen.com
Surface mining = simple mining: one machine cuts, crushes and loads the material in a single pass – the most cost-effective method of mining useful minerals.

- Highly selective mining without drilling and blasting
- Annual mining capacity of up to 12 million tons in soft rock, such as coal
- Made-to-measure cutting drums for soft rock and hard rock
- Different discharge conveyor lengths for loading heavy-duty trucks of up to 240 tons

To learn more about the biggest miner, visit www.wirtgen.com
The opening of MB’s new foreign subsidiary will be a “Stars and Stripes” event: the Vicenza-based company, world leader in the production and sale of crusher buckets, will inaugurate its new U.S. Headquarters in the first few days of April, with offices and warehouses specifically intended for its American customers.

The offices will be located in Reno, Nevada, in the western part of the United States, where many other companies of international scope have already set up their base: a strategic location, then, for all sale and distribution operations that MB will have to carry out in order to satisfy the already numerous market requests.

The opening of the U.S. branch represents, on the one hand, the conclusion of a thorough market analysis that has lasted a few years, and on the other a starting point for the already solid presence of MB’s products to take root on the market. The efforts aimed at conquering the American market began way back in 2005, when MB participated for the first time in the most important tradeshow for the building and territory construction sector, obtaining significant results which in time have turned into cooperation contracts with dealerships and private companies.

The success of MB’s crusher buckets has grown exponentially, even conquering the summits of the American Army: in fact, in 2008 the Vicenza-based company was awarded, through its dealer, a leading role in the construction project of 1645 homes and the renovation of an additional 443 housing units for U.S. Army families, one of the most important construction projects for privatised military housings in Italy since 1996.

In just a few years, then, MB has managed to conquer one of the most technologically advanced and creative markets, putting its touch of genius at the service of a customer base that is as demanding as it is large, made up of customers that have recognized in MB’s products an innovative and cutting-edge solution, with versatile use and extremely high productivity.

The new American subsidiary will allow MB to manage product sales and deliveries quickly and efficiently thanks to a large and technologically advanced warehouse, to meet customers’ requests through before-sales service and after-sales technical support delivered by English-speaking qualified personnel, with business hours from 8 o’clock in the morning to 8 o’clock at night.
From MB’s Reno-based office, it will be possible to implement marketing campaigns, collect market-related information, and schedule demonstrations and road shows for all possible customer segments.

However, the most important factor is that the new American branch will make it possible to have the buckets on site, ready to be delivered to the construction yard as quickly as possible, thus avoiding long transit times by sea.

Efficiency, determination, seriousness and reliability: this is how MB presents itself to the world, and it is how the company has wishes to conquer the American market, bringing work and innovation to this area. So, MB has no intention to stop now, and it is counting on further improving products and services already at the top in terms of reliability and performance, competing with different markets and cultures on a daily basis, thus strengthening and maintaining its position as unquestionable leader in the production and sales of its award-winning crusher buckets.
A new accessory that once again bears witness to the company’s relentless efforts to innovate and be innovative, creating work tools that are increasingly cutting-edge, flexible and of basic use, just like its unique crusher buckets.

Available in seven versions, depending on the excavator and the pin on which it is assembled, the new Universal Quick Coupling allows all kinds of equipment, from the crusher bucket to the hammer, from the traditional bucket to the drill, to the same excavator, with very short installation times.

This new product by MB therefore improves pick-up geometry by reducing the distance between the excavator arm and the equipment used, thus speeding up the jobs carried out on site.

And that is not all. The strain on the excavator is also diminished, thanks to reduction of more than 50% of the weight compared to traditional couplings offered on the market: suffice it to think that the new Universal Quick Coupling weighs about 80 kg, compared to the 150 kg of couplings available today on the market.

This universal coupling is quick and versatile and makes assembly operations easy thanks to the possibility of quickly assembling the pieces of equipment on both sides (front and back).

FOR MORE INFORMATION AND CONTACT:

MB S.p.A.
eMail: info@mbcrusher.com
Internet: www.mbcrusher.com

MB S.p.A.
MB S.p.A., the Vicenza-based company world leader in the production and sale of crusher buckets continues to amaze by always occupying a place in the front lines in the demolition and recycling sector, and the constant research by a competent team ensures that the company is always one step ahead by offering work tools that are an absolute must at construction sites.

The equipment offered by the company has made it extremely competitive and well-known at the international level in just a few years.
The St. Valentin, Austria based, and worldwide recognised, manufacturer of tracked mobile crusher and screeners, Hartl Anlagenbau GmbH, signed a co-operation agreement on the 23.02.2010 in Tangshan, China with Chinese cement giant Dunshi, part of the Jidong Development Group Co. Ltd. This multi-billion listed company employs over 20 000 people and is seen in China as a role model company.

In a high level meeting, that was attended by very high ranking officials from the Chinese government and business sector, the documents and agreements were signed that will see Hartl become the lead player in the distribution of crushing and screening plants in China.

The basis of this co-operation was the establishment of a joint venture company called „Hartl Jidong Crusher Manufacturing LLC“ headquartered in Tangshan, Hebei Province, PR of China. This 50/50 joint venture will in future allow the latest and most technologically advanced units to be built, and supplied to the Chinese market, using long term Know How and the Austrian high quality standards.

The production of the machines will be placed in the hands of Tangshan Dunshi Machinery Manufacturing Co. Ltd, who are one of the oldest, most respected and biggest producers in China. The headquarters alone has over 2500 employees and has the largest machining centres in the country as well as their own foundry.

In the new facility in Tianjan, where the Powercrusher machines will be produced, the production layout consists of four production halls, each totalling 75 000 m², a modern machining park as well as direct access to a port dock for the loading and unloading of products.

Production in China will save shipping, transport and import costs and allow entry into the world’s largest construction and construction machine market helping make the joint venture a competitive undertaking. One of the reasons for the planned serial production was to satisfy the Groups own needs, who own and operate cement works throughout the country and who will be supplied the latest mobile stone processing machines from the Hartl Company.
The beginning of the modernisation and replacement program from stationary to mobile plants will start with the purchase of 5 units, the 2 million Euro order was finalised and signed in the Austrian Headquarters.

The Austrians are extremely proud to have closed this order as well as the venture because after a long and intensive world wide analysis by the Chinese, who looked at both technology and competiveness, Hartl Powercrusher were chosen as the ideal partner.

After witnessing the capacities and quality of the Hartl machines, both in Austria and in various other countries, the cement specialists from China were convinced to move ahead with the Hartl products.

Basically, limestone must be broken down to 0/80mm and the units must produce – depending on the facility – between 300 and 500 tons per hour.

The soon to be supplied units will also have to produce various gradations to supply local asphalt and concrete producers. All of these requirements can be fulfilled using the PC1310I and PC1610I impactors because of their robustness and high production capacities.

The crushed material will then be fed to, the already ordered, tracked mobile screening plants for splitting into the required fractions.

National sales, local service and spare parts provision will be handled professionally and with immediate effect in China directly by Hartl in co-operation with the company Morningstar, headed up by Mr Gerald Sturmayt and Mr He Gang.

Both companies see the unique synergy effect and the enormous potential of working together, and are off to a great start with the signing of the Co-Operation Agreement shortly after the Chinese New Year- the year of the Tiger.
Laakirchen, May 2010. Thanks to its specialist know-how, SBM Mineral Processing has succeeded in winning a 2.2 million Euro order for a Diabas conveyance system from STRABAG Mineral Abbau GmbH. The system is to be put to use at the STRABAG quarry in Saalfelden, where diabas has been extracted since 1928. The order encompasses a system comprising conveyance and dosing belts as well as screens, with which track ballast is loaded onto HGVs and train wagons. The system capacity is 600 tons per hour - that roughly equates to the weight of 300 medium-sized cars being transported by the conveyor belts every hour.

The system is scheduled to go into operation in spring 2011. Diabas is an exceptionally hard and abrasion-resistant volcanic rock that is used in road construction and as track ballast.

Otto Biedermann, Managing Director of SBM Mineral Processing: „With this order we will be drawing on a whole range of rail loading projects that we have undertaken for the STRABAG group in the past. The newly placed order provides pleasing confirmation to my employees and I, that competence and quality is also highly valued in these financially challenging times.”

FOR MORE INFORMATION AND CONTACT:

SBM Mineral Processing GmbH
Mag. Barbara Krautgartner, MBA
Arbeiterheimstrasse 46
4663 Laakirchen | Austria
Tel.: +43 (0)76 13 - 27 71 160
eMail: Barbara.Krautgartner@sbm-mp.at
Internet: www.sbm-wageneder.at

Menedetter PR
Mag. Brigitte Mühlbauer
Stoß im Himmel 1
1010 Wien | Austria
Tel.: +43 (0)1 - 533 23 80
eMail: muehlbauer@menedetter-pr.at

About SBM:
As a manufacturer of preparation plants and conveyance systems for gravel, sand, ballast and similar materials, SBM Mineral Processing generates a turnover of over 50 million Euros and is internationally active with an export quota of 80%. SBM is one of the world’s market leaders in special areas. The product portfolio comprises individual machines, stationary and mobile systems as well as mobile concrete mixing systems and service & support. The company’s head office is situated in Laakirchen, Upper Austria.
“Knowledge and experience are important factors of success in the upstream-oriented raw material business. Even if the overall importance of Germany as a producer of raw materials is highly regressive, the port-based mining is still an important branch of mining, which has an internationally high score due to its high quality fertilizers. This importance is expected to increase in light of the globally increasing demand for fossil. Meanwhile there is a global "globalization", "security of raw material and energy", "sustainability" and "environmental protection" are occupying such a high secure situation. As distribution increases via new routes, through modern media like in on-line magazine becomes increasingly important. Particularly the complex aspects of the term "sustainability", which is defined as the balanced correlation between economy, ecology and social requirements, can only sufficiently be taken into consideration, if they are freely accessible to the concerned circle of people.”

— David Eming, Member of the Board E+S Aldingerellschaft

“Those days are only particular mineral commodities are rare, but also well trained engineers and specialists for extraction, processing and finishing of mineral commodities. This circumstance is the result of a development which not only has regulated the importance of this branch of industry for the economic and social development of the world. As an integral part of knowledge management, continuing education and transfer of technology are key success factors of a company. The current AMS takes stock of this need and offers modern solutions to a global network of specialists and advanced training of specialized staff. Furthermore it allows for a global exchange of experiences in the feedstock industry.”

— Markus Henning, Member of the Board WEG Power Management

“Advanced Mining Solutions provides a medium platform for clients, engineering businesses and for us as producers to exchange and effectively publish information at a global level. Our readers electronic media take more and more space. AMS responds to this challenge and also meets the current tasks of generating multi-media training and quick exchange of information in an uncomplicated way. We are anxious to follow the future development of this new medium and are happy to support the initiative.”

— Mr. Ing. Christian Hottschuch, Sales Manager Mining Consulting & Services, Rhenish-Westphalian Business Region

“In future, training of qualified personnel will be an even greater challenge for our industry. The advancement of technology keeps setting new standards for man and machine. New challenging deposits are being explored and developed. Therefore an information platform for our industry is a necessity.”

— Oliver Kid, Business Line Manager, Atlas Copco VTC GmbH

“Today the feedstock industry is the stimulus for social as well as economic developments. The globally skyrocketing demand for raw materials and their economic extraction through new technologies are in the daily spotlight. In addition, ecologic parameters round off the holistic spectrum of the subject on global raw material production. Advanced Mining Solutions takes up all these subjects. Uwe Prof. Dr. Horst Tennick is informing decision-makers in the feedstock industry about further training, practice and new developments through this on-line service, Advanced Mining Solutions fills in the gap of many professional journals on-line.”

— Frank Kreuter, Cornerstone Consulting

“The industry of raw material dependent world champion Germany has a two-fold mission to note the new internet publication: It communicates up-to-date news on project developments, which are important both for this supply of raw material, as well for export of machines and facilities. Furthermore it independently informs on procedure and technical innovations.”

— Bernhard van der Linden, Lincon Advisory & Consulting Services

“Please the masses of approximately 110 billion tons are being moved annually for extraction and processing of mineral commodities. Forecasts estimate that by 2050 these masses will increase to about 150 billion tons. The technological processes in mining require highly developed machines and facilities. The parallel use of modern machines and continuous training of specialized staff is the key to success of mining businesses. AMS takes up this need and offers an international audience for readers of this goal.”

— Manfred Schreiber, VDMA — German Engineering Federation e.V., Mining Equipment Association

“Mining is again socially taking the center stage, as a value creating industry. Rising demand and increasing prices of raw materials, changing technologies and high demand for new results in mining are early some of the prevailing themes. The concept of Advanced Mining Solutions Online will offer internet-based information, suggestions and technical reports of our industry, allowing the interested party quick access — which is fully in the spirit of our time.”

— Dr. Ing. Thomas Schäfer, President Committees, Sammel Mining and Construction

“One of the pillars of an effective feedstock industry is sound mining knowledge, based on multi-disciplinary studies. But the drastically increased demand mining has become a focus, after years of少爷 mining had returned into the focus, after years of scarcity. Of course, it is back into the focus of the industry, the investors and the public. As a result of increased demand for raw materials, new mines are not only being explored, but also developed in a number of countries, other than in the "big" mining countries. This is also happening in countries which can be found along the rich mining experience. The mining industry in particular makes a critical contribution to employment and to securing and improving the quality of life of all of us, primarily due to the mineral materials, but also due to its power of innovation and its immense potential for development in the sense of new technologies. This also happens because of share of the technological and other industrial areas. A concept like AMS online will be a media, useful tool to inform, secure current knowledge and experience broadly available, and as such to further develop this knowledge into other fields.”

— Ulrich Scholm, Business Manager Asia Germany MIC GmbH

“The need-based and continuous supply of relevant construction materials for the purpose of constructing and enhancing infrastructural establishments, which are the arteries of the economy, is an indispensable foundation for the performance of a society. As an example the high amount of used gravel and crushed stone, which are extracted in Germany, are processed in high, of the publicly financed construction above and below the ground, partially in road and traffic route construction. In order to secure the supply situation, the high quality, qualified personnel in the respective companies and enterprises are required, the new concept of AMS provides the opportunity to easily make available up-to-date knowledge and applicable information, and should therefore be at the disposition of all businesses and to increasingly exist.”

— Dito Huang, Dito Ceramic, Business Manager British Asphal GmbH, Member of the Board Brandenburg
FOR EACH DEMOLITION AND ODOR PROBLEM THE CORRECT SOLUTION

DEHACO LEADING SUPPLIER FOR DUST CONTROL

DEHACO INTERNATIONAL is a leading supplier of dust fighters. This company is one of the first, who response to the increasingly urgent need for solutions to the dust and odor problems which the demolition world and the recycling companies are still facing or will be facing in future. With the introduction of the large DE-DUST dust fighters in 2008, which are used for large demolition work in and around residential areas, and most recently the AXO and the NANO, which are suitable for light demolition work in buildings, Dehaco offers the largest selection of dust fighters for a variety of demolition work.

Remote control

Dehaco is convinced that the dust control is regulated more emphatically by law in the future. Reason enough for the company to look for better and more efficient solutions in this area. The developments in this field, and also the demand of the market for targeted applications are not stagnated. Dehaco is quickly and efficiently braced for this situation, for example with these new generation of DE-DUST dust fighters. The scope of these new dust fighters is now 0-150 meters.

New DE-Dust AXO

The DE-Dust AXO is also new. It is a midi-dust fighter, which is ideal for smaller outside demolition works and for the recycling industry, for example in a hall or on a conveyor belt. The AXO can be installed very easily, because it requires only 230 volt power and uses a rotor instead of water jets. The machine weighs 80 kg, has a water consumption of 0-200 liters / u and a range of up to 20 meters.

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DE- Dust Pico, NANO and Femto

The Pico is especially intended for demolition of buildings – it is now standard equipped with a switch to have the options of adjusting the water consumption between 4 and 8 liters per hour.

DE-NANO Dust is the big brother of the Pico and intended for demolition of larger rooms in buildings or for outside demolition of small objects. It sufficient to connect the Nano to the water- and power network. This model requires no compressed air. The water can be adjusted up to 80 liters per hour. By its weight of only 19kg the Nano can be easily transported. One important characteristic of the dust fighter is the large opening, which means that the risk of blockage is almost zero. Furthermore a pump is not necessary, which leads to a reliable and simple solution.

The mini-dust fighter Femto is suitable for demolition work in small rooms in buildings. Due to its small size, the Femto is easy to transport.

In summary we can say that Dehaco offers a complete line of dust fighters, which deals with the dust control problems in an excellent way. More information on Dehaco dust fighters you will find at: www.dehaco.eu.

Dehaco B.V. (Since 1985) Dehaco sells and rents an extensive range of hydraulic and pneumatic (demolition) products, asbestos removal and safety products. Moreover Dehaco has a modern testing station for accessories and asbestos tools. Large construction and demolition companies are part of the clientele. Dehaco is an ambitious company, whose goal it is to expand its range at home and abroad.
## The AMS-Event Calendar 2010

### July 2010

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Location</th>
<th>Website</th>
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<tbody>
<tr>
<td>30 Jun – 04 Jul 2010</td>
<td>13. International Mining &amp; Mining History Workshop</td>
<td>Sankt Andreasberg, Germany</td>
<td><a href="http://www.montanhistorik.de">www.montanhistorik.de</a></td>
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<tr>
<td>01 – 07 Jul 2010</td>
<td>Joint Meeting: GDMB Technical Committee Deposits – GDMB Technical Committee Commodity Economy/Raw Material</td>
<td>Halle, Germany</td>
<td><a href="http://www.gdmb.de">www.gdmb.de</a></td>
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<tr>
<td>07 – 09 Jul 2010</td>
<td>AGIT 2010: Symposium and Exposition Applied Geoinformatics</td>
<td>Salzburg, Austria</td>
<td><a href="http://www.agit.at/">www.agit.at</a></td>
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<tr>
<td>27 – 29 Jul 2010</td>
<td>QME 2010 – Queensland Mining and Engineering Exhibition</td>
<td>Mackay, Queensland, Australia</td>
<td><a href="http://www.aims.rwth-aachen.de/AIMS">www.aims.rwth-aachen.de/AIMS</a></td>
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### August 2010

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<th>Date</th>
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<tr>
<td>24 – 26 Aug 2010</td>
<td>Argentina Mining 2010</td>
<td>San Juan, Argentina</td>
<td><a href="http://www.argentinamining.com">www.argentinamining.com</a></td>
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### September 2010

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<th>Date</th>
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<tr>
<td>06 – 07 Sep 2010</td>
<td>Repeat Course Blasting</td>
<td>Clausthal-Zellerfeld, Germany</td>
<td><a href="http://www.fwz-clz.de">www.fwz-clz.de</a></td>
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<tr>
<td>06 – 15 Sep 2010</td>
<td>Basic Foundation Course Blasting</td>
<td>Clausthal-Zellerfeld, Germany</td>
<td><a href="http://www.fwz-clz.de">www.fwz-clz.de</a></td>
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<tr>
<td>08 Sep 2010</td>
<td>39. Geomechanics Colloquium</td>
<td>Freiberg, Germany</td>
<td><a href="http://www.tu-freiberg.de">www.tu-freiberg.de</a></td>
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<tr>
<td>09 – 10 Sep 2010</td>
<td>BulkSolids Europe 2010</td>
<td>Glasgow, Scotland</td>
<td><a href="http://www.burksolideurope.com">www.burksolideurope.com</a></td>
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<tr>
<td>12 – 15 Sep 2010</td>
<td>International Symposium Continuous Surface Mining Technique</td>
<td>Freiberg, Germany</td>
<td><a href="http://www.bergbau-tagebau.de">www.bergbau-tagebau.de</a></td>
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<tr>
<td>16 – 17 Sep 2010</td>
<td>GDMB-Technical Committee Processing and Environmental</td>
<td>Clausthal-Zellerfeld, Germany</td>
<td><a href="http://www.gdmb.de">www.gdmb.de</a></td>
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<tr>
<td>20 – 21 Sep 2010</td>
<td>“Computer use” in mining</td>
<td>Kassel, Germany</td>
<td><a href="http://www.gdmb.de">www.gdmb.de</a></td>
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<td>October 2010</td>
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<td><strong>04 – 08 Oct 2010</strong> Electra Mining Africa 2010</td>
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<td>Johannesburg, South Africa</td>
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<td><strong>05 – 07 Oct 2010</strong> iPAD DRC. Mining and Infrastructure Exhibition</td>
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<td>Congo, Democratic Republic of Congo</td>
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<td><strong>05 – 07 Oct 2010</strong> INTERGEO 2010. Conference and trade fair for geodesy,</td>
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<td>geoinformation and land management</td>
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<td>Cologne, Germany</td>
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<td><a href="http://www.intergeo.de">www.intergeo.de</a></td>
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<td><strong>19 – 21 Oct 2010</strong> GeoDarmstadt2010</td>
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<td>Darmstadt, Germany</td>
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<td><strong>19 – 21 Oct 2010</strong> Intensive seminar Geothermal energy: the development</td>
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<td>of geothermal energy projects</td>
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<td>Munich, Germany</td>
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<td><a href="http://www.hdt-essen.de">www.hdt-essen.de</a></td>
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<td>Ontario, Canada</td>
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<td><a href="http://www.cim.org/memo2010">www.cim.org/memo2010</a></td>
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<tr>
<td><strong>28 – 29 Oct 2010</strong> 7. Saxon geothermal–energy day</td>
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<tr>
<td>Torgau, Germany</td>
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<td><a href="http://www.gkz-ev.de">www.gkz-ev.de</a></td>
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Weiterbildungsangebot

Lehrgang für Fach- und Führungskräfte in der mineralischen Rohstoffindustrie

16. - 18.02.2011

Mittwoch, 16. Februar 2011

Planung und Projektierung
- Einführung in die Tagebautechnik
- Lagerstättenbewertung
- Rechtliche Rahmenbedingungen der Rohstoffgewinnung im Tagebau
- Tagebauprojektierung
- Tagebauzuschnitt und Abbauplanung
- Hauptprozesse der Rohstoffgewinnung im Tagebau

Donnerstag, 17. Februar 2011

Betriebsmittel und Prozesse der Rohstoffgewinnung
- Auswahl und Dimensionierung von Tagebaugeräten
- Lösen, Laden, Transportieren
- Betriebsmittel im Lockergestein (Sand und Kies, Braunkohle, Ton)
- Betriebsmittel im Festgestein (Naturstein und Kalkstein)
- Betriebsmittel in der Nassgewinnung

Freitag, 18. Februar 2011

Rohstoffaufbereitung
- Aufbereitung und Veredlung von Steine- und Erden
- Analyse
- Zerkleinern, Klassieren, Sortieren
- Entwässern, Trocknen

Dozenten
Univ. Prof. Dr.-Ing. habil. H. Tudeshki
Dr.-Ing. K. Freytag
Dr.-Ing. V. Vogt
Dipl.-Ing. T. Hardebusch

Teilnahmebedingungen
Der Tagungsbeitrag von Euro 1300,- (zzgl. ges. MwSt.) beinhaltet die Teilnahme an der Lehrveranstaltung.

Der Selbstkostenbeitrag für Getränke, Mittagessen und eine Exkursion mit Abendveranstaltung beträgt Euro 150,- (zzgl. ges. MwSt.).

Veranstalter und Organisator
Lehrstuhl für Tagebau und Internationaler Bergbau
Institut für Bergbau, TU Clausthal
Erzstraße 20
38678 Clausthal-Zellerfeld
Telefon: +49 (0) 53 23 / 72 22 25
Telefax: +49 (0) 53 23 / 72 23 71
http://www.bergbau.tu-clausthal.de
STEINEXPO 2011 — PREPARATIONS STARTED!

Who doesn’t have fond memories of the Steinexpo 2008 when more than 43,000 trade visitors passed through the gates of the demonstration exhibition for the building and building materials industry in the Niederofen Basalt quarry? It is hard to believe how fast the time has passed; the preparations for Steinexpo 2011 (31 August to 3 September 2011) have already begun. With the signing of the contract between the operator of Europe’s largest basalt quarry in Homberg/Niederofen, the Mitteldeutsche Hartstein-Industrie MHI, and the organisers of the Steinexpo to use the stone quarry as a fairground, the next event is now a reality again.
Impressive record

The last steinexpo closed with the desired measure of success: 43,280 visitors represented an enormous increase in the number of visitors. The approximately 230 exhibitors representing around 360 brands were highly satisfied with the reactions to their demonstrations and exhibits. Visitors were particularly impressed with the active performance shows of the different machinery and plants. The high trade visitor share of more than 90% received a very positive response from exhibitors, as it provided for intensive professional and technical exchange of information. The exhibitors also appreciated the international character of the visitor composition (20.9%).

Multiple offers and innovations

This is already the eighth demonstration exhibition for the building and building materials industry to take place in Homberg/Niederofleiden in Marburg from 31 August to 3 September 2011. That will again make Europe’s largest basalt quarry the most eventful meeting point for the building materials industry. With an expected net exhibition area of approximately 50,000 square meters, the steinexpo 2011 offers manufacturers, vendors and suppliers across the spectrum of raw material extraction, processing, refining and recycling of construction materials the ideal platform for presenting their products, services and innovations live.

Here, the large halls, which form an important part of the steinexpo in addition to the outdoor demonstration possibilities, are centrally integrated into all the fair events by their placement on the main area.

Powerful partners

As with the last event, the Association of German Machinery and Plant Manufacturers (VDMA) is again the technical and conceptual partner of steinexpo 2011. The German Association of Mineral Resources (MIRO) is also actively involved in the design, publication and implementation of the demonstration show. The same applies to the German Association for Construction Industry Engineers and Professionals (VDBUM). The European commitment to the steinexpo is supported by the partnership with the European Association of Building Materials UEPG (European Aggregates Association), representing approximately 32,000 businesses. Media partnerships with leading national and international trade journals complete the picture.

A “special” fairground

The spatial changes to the Niederofleiden stone quarry – we’re dealing here with an actively producing business – will give the fairground a completely new “face” in the coming year. The envisaged changes again promise impressive and practical presentations by exhibitors and make this “special” fairground even more attractive.

All in all: The steinexpo 2011 will again be the meeting point for the European building and building materials industry from 31 August to 3 September 2011.

Exhibition documentation is already available from:

Geoplan GmbH
Josef-Herrmann-Straße 1-3
76473 Iffezheim | Germany
Tel.: +43 (0)72 29 - 606 - 30
Fax: +43 (0)72 29 - 606 - 10
eMail: info@geoplanGmbH.de
Internet: www.geoplanGmbH.de

FOR MORE INFORMATION AND CONTACT:

The steinexpo 2011 again takes place from 31 August to 3 September 2011 in Europe’s largest basalt quarry in Homberg/Niederofleiden near Marburg in Germany.
Profil

Seit 1976 kommen traditionell alle zwei Jahre Experten aus dem nationalen und internationalen Bergbau aber auch verwandten Branchen in Clausthal zusammen, um Erfahrungen, Erkenntnisse und Entwicklungen zu auszutauschen und zu diskutieren.


In den vergangenen Jahren konnten wir durchschnittlich 300 Fachbesucher in Clausthal anläßlich unseres Kolloquiums und die begleitenden Fachausstellung begrüßen.

Vortragssammlung
Unserer 35-jährigen Tradition folgend, möchten wir Ihnen den Teilnehmern auch dieses Mal hochkarätige Vorträge sowohl aus Wissenschaft und Forschung, vor allem aber aus der betrieblichen Praxis bieten.

Wir wollen Sie daher auffordern, selbst aktiv mit einem Vortrag an der Veranstaltung teilzunehmen. Interessant sind vor allem Vortragsthemen, die die Anwendung der Bohr- und Sprengtechnik in den verschiedensten Einsatzgebieten aus Anwendersicht vorstellen und besondere Herausforderungen oder die Anwendung neuer Technologien schildern.

Das Papier sollte mind. 1 Seite, aber höchstens 8 Seiten umfassen. Eine kurze Zusammenfassung am Beginn des Beitrags wäre hilfreich, ebenso Tabellen, Grafiken und Bilder. Zusätzlich sollten Angaben zur Person des Vortragenden, idealerweise ein kurzer Lebenslauf sowie die Kontaktdaten ergänzt werden.

Alle akzeptierten und präsentierten Beiträge der Konferenz werden in einem Tagungsband und im Magazins AMS ONLINE Advanced Mining Solutions veröffentlicht.


Sonstiges
Im Rahmen des Kolloquiums wird ebenfalls eine Fachausstellung stattfinden. Hierzu stehen Ausstellungsflächen für 80 €/m² zur Verfügung.

Alle Beiträge des Kolloquiums werden in einem Tagungsband sowie in dem Magazin AMS ONLINE Advanced Mining Solutions veröffentlicht.

Sprengtechnik im Oberharzer Bergbau auch 380 Jahre nach der ersten Anwendung der Bohr- und Sprengtechnik in den verschiedensten Einsatzgebieten aus Anwendersicht vorstellen und besondere Herausforderungen oder die Anwendung neuer Technologien schildern.

Zimmerreservierung
Bitte wenden Sie sich für Zimmerreservierungen direkt unter dem Stichwort „BUS 2011“ an:

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Harzhotel zum Prinzen (0 53 23) 9 66 10
Landhaus Kemper (0 53 23) 17 74
Pension am Hexenturm (0 53 23) 13 30

Oder an die Tourist Information:
Telefon: (0 53 23) 8 10 24
Email: info@harztourismus.com
Internet: www.harzeranzett.de
EXECUTIVE MANAGER
Minka Ruile

PUBLISHER
Prof. Dr.-Ing. habil. Hossein H. Tudeshki
University Professor for Surface Mining and International Mining
eMail: tudeshki@advanced-mining.com

EDITORIAL TEAM
Prof. Dr.-Ing. habil. Hossein H. Tudeshki
Dr. Monire Bassir
Dipl.-Umweltwiss. Christian Thometzek
eMail: redaktion@advanced-mining.com

DESIGN & LAYOUT
Dipl.-Umweltwiss. Christian Thometzek
eMail: Christian.thometzek@advanced-mining.com

BANK CONNECTION
Bank: Sparkasse Aachen, BLZ 390 500 00
Account-No.: 1070125826
SWIFT: AACSDDE3
IBAN: DE 273905000101070125826

GRAPHICAL DESIGN
Graumann Design Aachen
Dipl.-Des. Kerstin Graumann
Augustastr. 40 - 42
52070 Aachen | Germany
Tel.: +49 (0) 241 - 54 28 58
Fax: +49 (0) 241 - 401 78 28
eMail: kontakt@graumann-design.de
Internet: www.graumann-design.de

PROGRAMMING INTERNET SITE
79pixel
Steffen Ottow, B.Sc.
Scharenbergstr. 24
38867 Bad Harzburg | Germany
Tel.: +49 (0) 53 22 - 8 19 38
eMail: steffen@79pixel.de
Internet: www.79pixel.de

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