Optimization of geo-mechanical-structural drilling with diamond crowns

Optimizacija geomehansko strukturnega vrtanja z diamantnimi kronami

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Abstract: For successful projecting and performance in all segments of mining, geo-technological and construction projects relating or depending on rock conditions where work is going on, quality geo-mechanical-structural drilling is of extreme importance. In article special attention will be focused on performing research drilling using diamond crowns because this is the way how most quality samples of rock which are later on fully examined in laboratory, can be obtained. Significance of optimal drilling for geo-mechanic-structural wells will be presented.

Izvleček: Za uspešno projektiranje in izvajanje del pri vseh segmentih rudarskih, geotehnoloških in gradbenih projektov, ki se nanašajo oz. so odvisni od pogojev hribine v kateri se izvajajo, je izjemnega pomena izvajanje kvalitetnega geomehansko-strukturnega vrtanja. V članku se bomo predvsem osredotočili na izvajanje raziskovalnega vrtanja z uporabo diamantnih kron, saj na ta način pridobimo najkvalitetnejše vzorce hribin, ki jih nato lahko detajlno preiščemo v laboratoriju. Prikazali bomo pomen optimalnega načina vrtanja pri izvedbi geomehansko-strukturnih vrtin.

Key words: research drilling, crown loading, crown, core
Ključne besede: raziskovalno vrtanje, obremenitev na krono, krona, jedro

INTRODUCTION

For successful projecting and performance in all segments of mining, geo-technological and construction projects relating or depending on rock conditions where they are carried out, quality geo-mechanical-structural drilling is of extreme importance. In article special attention will be focused on performing research drilling using diamond crowns since in this way most quality samples of rock which will be fully examined in laboratory, can be obtained. Significance of optimal drilling for geo-mechanical-structural wells will be presented.

CORE SAMPLING

Core sampling is a process of drilling using drilling devices with advancing tool construction shaped in a way which enables them to take rock and soil samples. Sample – core is accumulated in a special tube, called core tube, which enables to bring the sample to surface. The aim of core sampling is gaining quality, intact core suitable for further research in laboratory. Drilling method and used equipment have major influence on core quality. Less influence to the core quality is later produced by manipulating with core in course of investigation.

In Slovenia in general a so called core tubes made according to Swedish (Craelius) metric standard are used. Core tube diameters move from 36 mm to 146 mm.

The following core barrels are in use:

- single tube core barrel;
- double tube core barrel;
  - rigid double tube core barrel
  - double tube core barrel with bearing
- three wall core tube;
- core sampling according to "wire line".

CORE SAMPLING WITH CORE CROWNS AND CORE TUBES

At core sampling an optimum among the following parameters is striven for:

- rotation speed of drilling accessories and tool;
- force magnitude on crown;
- ways of well flushing out (quantity, pressure, quality and flushing type).

Regarding soil and rock properties we can state the following:

1. Because of great diversity in soil and rock quality the probability of proper advancing speed determination is low irrespective of small number of drilling parameters. Rock materials are complex and heterogeneous. Although micro-structure and composition (minerals, grain size, bonds between grains etc.) are the same, macrostructure (cracks, frequency etc.) varies because of different factors such as surface loadings which affect advancing speed.

2. Crown activity on rock material influenced by various drilling parameters is mutually dependent and complex.
   Independent variables while drilling are the following:

- characteristics of drilling tools – crown (number, shape and size, used matrix and geometry of the crown) rock type (hardness, solidness, abrasion, mineralogical composition, cracks etc.);
- drilling method (moments, axis force, rotation speed etc.).

  Dependent variables that affect drilling advancement are:

- wear out of teeth;

- rock fracture;
- detritus size and shape;
- input specific energy during drilling.

3. Characteristic wear-out of teeth is defined by the drilling mode:

- Drilling advancement (m/h) unsuitable;
- Loading on single tooth is too low so teeth have not adequate contact with rock. Teeth penetration obstructed dew to increased surface arising from polishing teeth and getting blunt. Friction between teeth and rock is low.
- Drilling by too high loading on crowns resulting in teeth breaking, high friction, unsuitable well washing out, unsuitable crown cooling and well bottom cleaning. Penetration speed does not grow up resulting in so called burning drilling crown.

Optimal drilling advancement (m/h):

- Rock fracturing and borehole particles formation uniform and constant.
- Teeth and crown matrix wear out evenly, adv ancement, number of revolutions and loading on crown are also even.

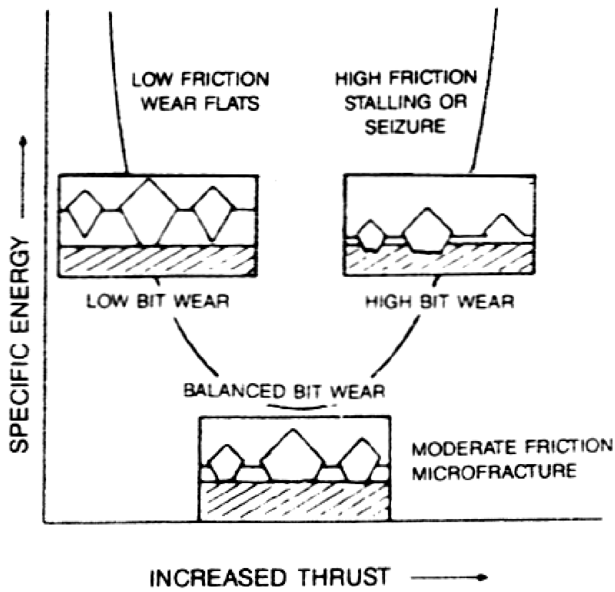


Figure 1. Presentation of drilling crown tooth wear out in dependence of loading
Slika 1. Prikaz obrabe zob vrtalne krone v odvisnosti od obtežbe

Regarding above stated facts we can conclude:

- Loading of the crown is at optimal drilling dependent on strength and hardness of the rock and on teeth and crown conditions.
- Equilibrium between wear out of teeth and crown begins at maximal

advancement at optimal loading which is a little over minimal needed specific energy by individual drilling mode and rock type.
- Wear out of teeth is the best indicator on drilling mode.
- Teeth of smaller dimensions require higher loadings for effective drilling, achieve better advancements and produce finer particles detritus.
- Tests and investigations showed that major part of input energy is not used for rock fracturing but for secondary crushing and grinding of bore particles. Therefore quality washing out of well bottom and bore quantity are very important.
- Work done for crown loading is much smaller than the work input to overcome the torque.

For better understanding of entire drilling mode operation it is necessary to show the principle of tooth crown cutting. Drilling mode is described in following phases:

• Ploughing
In very soft formations teeth can penetrate into rock and cause local overcoming of shear strength as shown in Figure 2. During crown rotation around axis and loading action on it teeth scratch bottom surface of the well like plough while ploughing field. Axial loadings are higher than shear ones so major part of work is done by axial loading. Provided that teeth are set in matrix in way that one furrow overlaps the other one the next tooth pushes some particles of the former tooth and the depth of furrow is equal as at former - in this case crown advances into rock. It is very important to wash out relatively big particles of the borehole.

• Stress relaxation
Stress relaxation occurs when pressure strength of the rock is high and static loading on single tooth is too low for immediate penetration into rock. Fracturing is triggered by tension discharge in the tooth furrow when the furrow traversed and caused a series of characteristic cracks and their widening as shown in Figure 2. In general a tooth during cutting never penetrates into rock if the latter had not been damaged before.

• Grinding, abrasion
In final phase grinding and abrasion are present and used at drilling into very hard rocks and at very high rotary speed. In principle that mechanism is very similar to mechanism of tension relaxation, the only difference are much more shallow cracks present here.

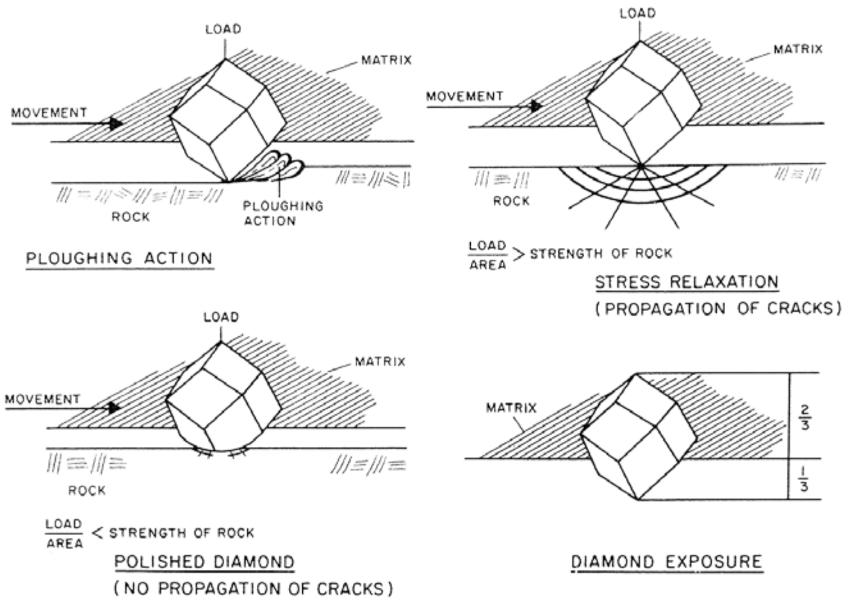


Figure 2. Operation of crown tooth depending on loading
Slika 2. Delovanje zob vrtalne krone v odvisnosti od obtežbe

For rock demolition crown tooth has to operate in accordance to the following principle:
1. Under influence of axial loading single crown tooth impresses into rock
2. Crown's turning torque generates shear force which fracturing the rock

Axial loading on single tooth is given by the equation:

$$F_0 = \frac{F}{m} \tag{1}$$

Where is:
F_0 - axial loading on single tooth [N]
F - axial loading on whole crown created by drilling device [N]
m - number of crown teeth [/]

Advancement into rock is possible only under condition:

$$F_0 > S \cdot \sigma_p \tag{2}$$

Where is:
F_0 - axial loading on single tooth [N]
S - touching surface of tooth [m^2]
σ_p - one axis pressure strength of rock [N/m^2]

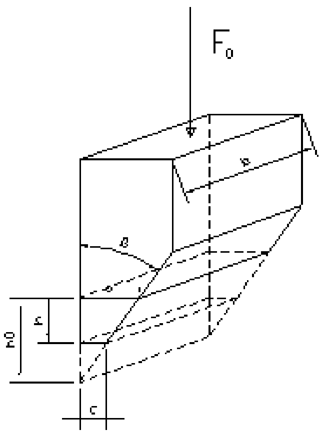


Figure 3. Crown tooth with technical elements
Slika 3. Zob krone s tehničnimi elementi

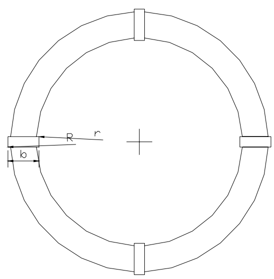


Figure 4. Scheme of the crown with teeth
Slika 4. Shema krone z zobmi

$$S = b \cdot c \tag{3}$$

Where is:
b - tooth width [m]
c - tooth thickness [m]

Tooth width is therefore given by expression:

$$b = R - r \tag{4}$$

Where is:
R - external crown radius [m]
r - internal crown radius [m]

In case of a new and unused tooth its surface is given by expression:

$$S = a \cdot b = h_0 \cdot tg\beta \cdot (R - r) \tag{5}$$

Where is:
β - sharp edge angle of tooth [°]
h_0 - penetration depth of tooth into rock [m]

Axial loading on single tooth is equal to expression:

$$F_0 = S \cdot \sigma_p = h_0 \cdot tg\beta \cdot (R - r) \cdot \sigma_p \Rightarrow h_0 = \frac{F_0}{tg\beta \cdot (R - r) \cdot \sigma_p} \tag{6}$$

In this case at m number of teeth in crown and n number of crown revolutions, advancement in a unit of time is:

$$L_{0-t} = h_0 \cdot m \cdot n \cdot t = \frac{F_0 \cdot m \cdot n \cdot t}{tg\beta \cdot (R - r) \cdot \sigma_p} = \frac{F \cdot n \cdot t}{tg\beta \cdot (R - r) \cdot \sigma_p} \tag{7}$$

Where is:
b - tooth width [m]
c - tooth thickness [m]
β - sharp edge angle of tooth [°]
h_0 - penetration depth of tooth into rock [m]
R - external crown radius [m]
r - internal crown radius [m]
t - time of crown operation until teeth wear out [s]
n - number of tool revolutions [rev/s]

It seems that during drilling when tooth traverses very cracked regions cutting depth is very small compared to crack size. This shows a more complex relaxation system of rock and removing borehole than foreseen from the above stated drilling modes.

It is very likely that in praxis the turning and tension relaxation mechanism is used in every softer rock formation. Every time when tooth travels across a furrow it causes changes according to the same principle of drilling mode under surface.

Operational effect of every drilling mode depends on hardness and rock tension and relations among tooth hardness, rock grain size and rock non-homogeneity.

Drilling modes mentioned above do not consider washing out of detritus from the crown operation area. Nevertheless experiences show how great influence washing out, tool cooling, flushing medium leading mode, quantity of washed medium etc. have on gained core quality, advancing speed and wear out of drilling tools and accessories.

INFLUENCING FACTORS ON CORE SAMP-LING QUALITY

From the drilling theory we know that the following factors have major influence on advancement speed:
- rotational speed;
- single tooth penetration depth into rock;
- physical mechanical properties of rock;
- drilling tool loading;
- teeth shape and conditions in tool;
- rinsing medium quality, flow and type.

Cutting speed

Drilling tool rotational speed has great influence on cutting speed. For quicker and more convenient calculation of cutting speed we can assume that it is equal to:

$$v = \pi \cdot D \cdot n \tag{8}$$

Where it is:
v - cutting speed [m/min]
D - drilling tool diameter [m]
n - number of tool revolutions [rev/min]

Figure 5 shows a graph for quick determination of cutting speed regarding rotational speed and tool diameter.

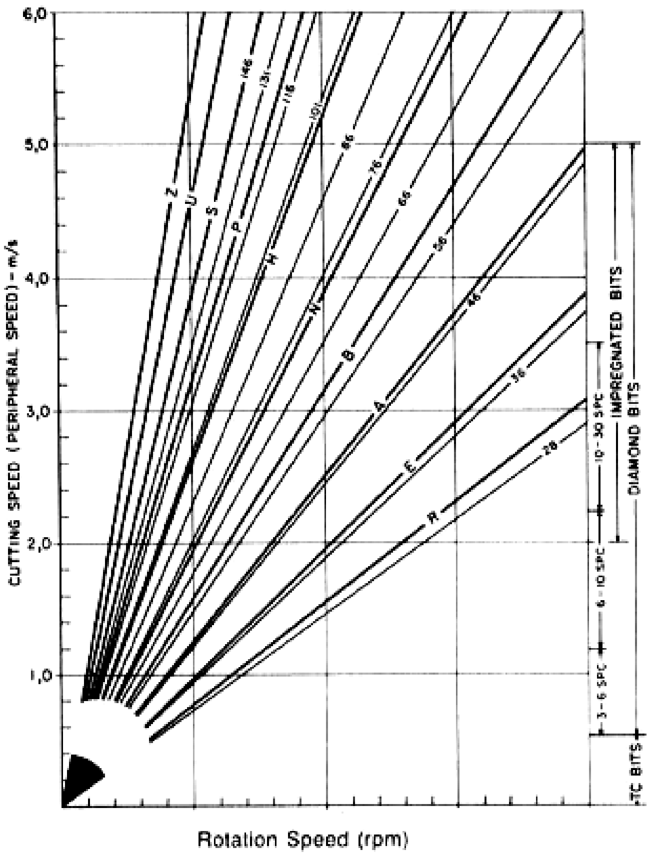


Figure 5. Graph for cutting speed determination
Slika 5. Graf za določitev hitrosti rezanja

Lower or higher speed has influence on advancement speed but it depends on rock formation properties. Final rotational speed is determined during drilling and mainly depends on rock properties and drilling techniques used.

Crown loading

Proper loading of tool – crown, is as important as proper rotational speed. During drilling crown loading is most easily determined by multiplying teeth number and the force that single tooth can withstand. This force is dependent on single tooth material quality.

As shown above axial loading on single tooth is equal to the expression:

$$F_0 = S \cdot \sigma_p = h_0 \cdot tg\beta \cdot (R-r) \cdot \sigma_p \Rightarrow h_0 = \frac{F_0}{tg\beta \cdot (R-r) \cdot \sigma_p} \tag{9}$$

In this case at the number of crown teeth *m* and crown number of revolutions *n* time advancement is equal to:

$$L_{0-t} = h_0 \cdot m \cdot n \cdot t = \frac{F_0 \cdot m \cdot n \cdot t}{tg\beta \cdot (R-r) \cdot \sigma_p} = \frac{F \cdot n \cdot t}{tg\beta \cdot (R-r) \cdot \sigma_p} \tag{10}$$

In a definite time t crown teeth wear out for an amount y. Therefore tooth height effected by axial force F_0 equals to:

$$h = h_0 - y \tag{11}$$

Where it is:
h_0 - height of a new and unused tooth [m]
y - tooth wear out [m]

Tooth wear out extent in time t can be expressed by equation:

$$v = \frac{y^2 \cdot tg\beta \cdot (R-r)}{2} \tag{12}$$

Tooth alloy material wear out can be expressed by:

$$v = \omega \cdot A \tag{13}$$

Where it is:
ω - coefficient of volume tooth friction wear out on every Nm [m^3/Nm]

Friction work for thin wall crown in time t can be expressed by equation:

$$A = F_0 \cdot f \cdot \pi \cdot (R+r) \cdot n \cdot t \tag{14}$$

Where it is:
f - coefficient of friction between rock and tooth

The last expression can be put into equation for tooth material wear out so we get the following:

$$v = \omega \cdot F_0 \cdot f \cdot \pi \cdot (R+r) \cdot n \cdot t$$

$$v = \frac{y^2 \cdot tg\beta \cdot (R-r)}{2} \tag{15}$$

Equalizing both equations we get:

$$\frac{y^2 \cdot tg\beta \cdot (R-r)}{2} = \omega \cdot F_0 \cdot f \cdot \pi \cdot (R+r) \cdot n \cdot t \tag{16}$$

Arranging the equations can express tooth wear out extent by:

$$y = \sqrt{\frac{2 \cdot \omega \cdot F_0 \cdot f \cdot \pi \cdot (R+r) \cdot n \cdot t}{tg\beta \cdot (R-r)}} \tag{17}$$

If we know values of ω and f we can determine tooth sharpness loss (bluntness) in time t and tooth penetration depth into rock material under influence of axial force F_0 in the same time t.

Actually it is $h = h_0 - y$ as shown in the Figure 6.

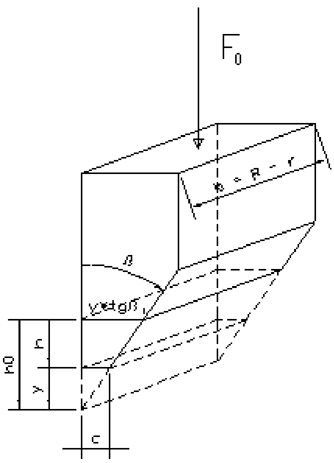


Figure 6. Crown tooth with technical elements with geometrical laws taken in account
Slika 6. Zob krone s tehničnimi elementi ob upoštevanju geometrijskih zakonitosti

Considering tooth wear out it follows:

$$h = \frac{F_0}{\sigma_p \cdot (R-r) tg\beta} - \sqrt{\frac{2 \cdot \omega \cdot F_0 \cdot f \cdot \pi \cdot (R+r) \cdot n \cdot t}{tg\beta \cdot (R-r)}} \tag{18}$$

Productive crown work will cease when $h = h_0 - y$. In this case penetration will go just by grinding where advancements are very low.

In this case $h_0 = y$

So:

$$\frac{F_0}{\sigma_p \cdot (R-r) tg\beta} = \sqrt{\frac{2 \cdot \omega \cdot F_0 \cdot f \cdot \pi \cdot (R+r) \cdot n \cdot t}{tg\beta \cdot (R-r)}} \tag{19}$$

Solving equation after time t and using relation $F \cdot m$ for axial force F_0 we get crown working time until teeth bluntness.

$$t_{\max} = \frac{F_0^2 \cdot tg\beta \cdot (R-r)}{\sigma_p^2 \cdot (R-r)^2 \cdot tg^2\beta \cdot \omega \cdot 2 \cdot F_0 \cdot f \cdot \pi \cdot (R+r) \cdot n} = \\ = \frac{F}{2 \cdot \sigma_p^2 \cdot tg\beta \cdot \omega \cdot f \cdot \pi \cdot (R+r)(R-r) \cdot n \cdot m} \tag{20}$$

From the above expression it follows that we can increase crown working time t_{max} by increasing axial force F proportionally with crown teeth bluntness.

With regard to above stated expression we can conclude:

- crown working time until teeth bluntness t_{max} quickly falls by increasing one axial pressure rock strength σ_p;
- increasing number of teeth in crown m shortens crown working time to bluntness t_{max}.

Data about single tooth loading capability can be obtained from crown manufacturer. In practice it applies that loading on single tooth should be 2/3 of maximal allowed loading.

Advancement speed

The most important parameter in drilling practice is exactly advancement speed provided that the other costs (e.g. tool and equipment) of achieving fastest progress are acceptable or as low as possible.

During drilling we must find optimal rotational speed, tool loadings and rinsing for every rock formation separately.

Crown advancement time until full teeth wear out can be expressed, provided we add meaning of t_{max} for time t, from above expression. We get following:

$$L_{0-t} = \mathrm{n} \cdot \mathrm{t}_{\max} \cdot \left(\frac{F}{\sigma_p \cdot (R-r) \cdot tg\beta} - \frac{2}{3} \sqrt{\frac{2 \cdot \omega \cdot F \cdot f \cdot \pi \cdot (R+r) \cdot n \cdot m \cdot t_{\max}}{(R-r) \cdot tg\beta}} \right) =$$

$$= \frac{\mathrm{F} \cdot \mathrm{n} \cdot \mathrm{F}}{\sigma_p \cdot (R-r) \cdot tg\beta \cdot 2 \cdot \sigma_p^2 \cdot tg\beta \cdot \omega \cdot f \cdot \pi \cdot (R+r)(R-r) \cdot m \cdot n}$$

$$-\frac{2}{3}\sqrt{\frac{2 \cdot \omega \cdot F \cdot f \cdot \pi \cdot (R+r) \cdot n^3 \cdot m \cdot F^3}{(R-r) \cdot tg\beta \cdot 8 \cdot \sigma_p^6 \cdot tg^3\beta \cdot \omega^3 \cdot f^3 \cdot \pi^3 \cdot (R+r)^3 \cdot (R-r)^3 \cdot m^3 \cdot n^3}} =$$

$$= \frac{F^2}{6 \cdot \sigma_p^3 \cdot tg^2\beta \cdot m \cdot \omega \cdot f \cdot \pi \cdot (R-r)^2 (R+r)} \tag{21}$$

Mean drilling speed in time t_{max} can be calculated by dividing equation for advancement L_{0-t} with the equation for crown advancement time to the point of absolute teeth wear out t_{max}.

$$v_{sr} = \frac{L_{0-t_{\max}}}{t_{\max}} = \frac{1}{3}\frac{F \cdot n}{\sigma_p \cdot tg\beta \cdot (R-r)} \tag{22}$$

From the equation for mean drilling speed we can conclude that the advancement speed is proportional to axial force of the crown on the rock.

Investigations have shown that advancement speed does not change proportionally to axial force increase but even more intensively and that the connection of above stated factors is much more complex.

Rinsing type and characteristics

All previous derivations about advancement speed and tool loading were based on the presumption that removing borehole particles, rinsing and tool cooling is always good.

In practice we know that flushing effect is rarely ideal. It depends on:
- crown shape and diameter;
- pole diameter;
- well conditions;
- used rinsing medium type;
- core tube and drilling pole diameter ratio.

Drilling fluid in phase of core sampling the following important functions:
- removal of drilling particles from the well;
- cleaning of well bottom and removing particles from crown teeth activity area;
- crown cooling;
- greasing and improving cutting process;
- protection of well walls where needed;
- friction reduction during drilling pole rotation;
- decreasing vibrations.

In any case the most important drilling fluid functions are cooling drilling tool and removing drilled particles. On basis of these functions we calculate the necessary quantity of drilling fluid.

The drilling fluid is pumped through drilling poles and the space between outer and inner tube of the core tube to the crown where it proceeds to the bottom of the well and, together with drilled material in annular between core tube and well walls, to the surface.

We have to make sure that the flow velocity of lifting drilling fluid and drilled material in annular is higher than sinking speed of largest particles of detritus. Quantity of the drilling fluid must ensure suitable tool cooling - in the hard rock, the more fluid is necessary for cooling the tool.

Usually flow rate in annular move from 0.3 to 0.5 m/s. Flow rate in annular is dependent mainly on rock density and drilled grain size and on rinsing density and viscosity.

CHOICE OF A DRILLING TOOL - CROWN

Primary aim of core sampling is getting quality cores from any depth in any rock formation. Quality of gained core is a function of used drilling techniques (conventional core sampling, wire line), choice of proper drilling tool for formations we are drilling through and choice and equipment of core tube.

The choice of proper crown for core sampling in individual rocks is a matter of experienced operator. This is especially important when using diamond crowns. In general same principles of drilling crown choice apply for both prevailing crown types i.e. crowns made of carbide materials and diamond crowns.

Crowns from carbide materials

In general these crown types are used only in incoherent and soft materials since carbide inserted pieces wear out rapidly. Their use is slowly giving up in the world. Particular crown selection is limited to size and teeth distribution and crown wall thickness.

Diamond crowns

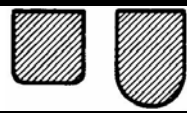
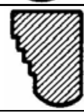
Selecting a diamond crown which will be used in particular rock formation requires an experienced operator. Besides the fact that diamond crowns are expensive consumer goods, proper choice enables faster advancement and gaining more quality cores. Diamond crowns are characterized by following:

- geometrical and cutting profile;
- number, distribution and size of diamonds in crown;
- matrix characteristics into which diamonds are built-in.

Geometrical and cutting crown profile

Crown must be shaped in the way to ensure even and effective rock cut. Crown teeth must be well cooled and drilled material needs to be removed immediately.

Ideal crown cutting width is as narrow as possible. Because of their characteristics some rocks to a certain degree dictate the width and height of cutting profile. Cutting profiles are shown in Figure 7.

Crown with on-surface inserted teeth	
Flat, rounded profile Standard profile with good efficiency	
Semicircular profile Profile resistant to use in cracked formations	
Graded profile High advancements in fragile and cracked formations	
Pointed profile Good advancements, more resistant than graded profile	
Pilot profile Good well stabilization, usable in medium hard formations	
Bi-conical profile For thin wall crowns, usable in soft and uncracked formations	

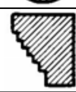
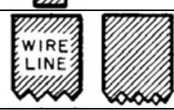
Impregnated crowns	
Flat profile Standard profile for thin wall crowns, usable in very hard and cracking formations	
Semicircular profile Standard profile for thick wall crowns, usable in hard and cracking formations	
Graded profile Profile for thick wall crowns, usable in very hard formations	
Pointed profile Good advancements	
Double graded profile Profile usable only for thick wall crowns	
Saw shaped profile Usable in very hard uncracked formations	

Figure 7. Typical cutting profiles of diamond crowns
Slika 7. Tipični rezalni profili diamantnih kron

Supplying drilling fluid on the crown is performed through so called floshing channels or ways situated in the crown. Number of those channels depends on the rock we are drilling. Crowns for softer materials have more flushing channels than crowns for harder materials. Number and shape of flushing channels have great influence on crown geometry.

Number, distribution and teeth size in a crown

Size, number and distribution of teeth is dependent mostly on rock formations we shall drill through.

Tooth size in crown is directly dependent on rock material hardness. The harder material is, the smaller grains and the larger number of diamonds are in the crown.

Teeth are inserted into crown in patterns. Where the teeth are on-surface inserted furrow (made by teeth) overlapping must be assured. Therefore particular pattern of inserted teeth depends on their size.

Characteristics of matrix in which teeth are inserted

Purpose of matrix in which teeth are inserted is to keep them as long as they effectively cut stoneware and to ensure stabile connection with crown body.

Crowns with on-surface inserted teeth must have matrix resistant to abrasion arising from particles of drilled rock. These matrixes are made of tungsten carbide connected by copper alloy.

Matrix composition must be adapted to rock material and tooth size in crown. In general problems arise from matrix wear out in softer material where abrasion generated by drilled particles very high. In this case teeth begin to fall out before they are worn out. Improper matrix wear out is one of indicators of well rinsing quality.

By impregnated matrixes teeth must be evenly distributed in matrix body. Matrix material must be evenly wear out together with teeth enabling that new surfaces are opening by unused teeth.

REVIEW OF DRILLING PARAMETERS AT RESEARCH DRILLING FOR A BIG UNDERGROUND ROOM MAKING PROJECT

For determination of rock composition in the area where we plan to make large cavern a geo-mechanical – structural drilling was performed. In the area of investigations of limestones, dolomites and breccias with thin insertions of marl have been altering. According to mapping and geophysical measurements various layers quickly alter between themselves, from geo-mechanical viewpoint they do not differ significantly. RMR values range this part in the medium class of rock quality. Drillings are performed using diamond crowns and double tube core barrels. The well was made to 246 m depth. For our analysis on suitability and determination of optimal drilling parameters with diamond crowns it was important that we had besides exact presentation of drilling by means of drilling reports, available many data from laboratory investigations of core samples. In the Table 1 there is a list of samples investigated in laboratory.

Table 1. List of core samples for laboratory investigations and results of one axis pressure strength
Tabela 1. Popis vzorcev jedra za laboratorijske preiskave in rezultati enoosne tlačne trdnosti

Depth [m]	**Description**	**One axis pressure strength cylinder σ_c [MPa]**
30.5 - 30.8	limestone	35.2
64.2 - 64.6	marl breccia	17.2
71.4 - 71.6	breccia with marl	24.6
98.0 - 98.6	marl dolomite	31.6
118.2 – 118.5	limestone breccia	37.7
124.3 - 124.6	dolomite marl breccia	31.9
130.1 - 130.5	dolomite breccia	30.4
134.0 - 134.3	dolomite breccia	40.1
142.0 - 142.4	dolomite	16.1
152.4 - 152.6	dolomite breccia	32.7
153.5 - 153.7	dolomite breccia	61.7
155.7 - 156.0	dolomite breccia	27.1
171.0 - 171.2	dolomite breccia	73.7
177.7 - 178.0	dolomite limestone	65.3
179.7 - 180.0	breccia dolomite	89.5
183.8 - 184.0	breccia dolomite	94.3
184.0 - 184.3	dolomite limestone	56.4
187.7 .- 188.0	dolomite breccia	96.0
192.4 - 192.6	dolomite breccia	102.9
193.5 - 193.7	breccia dolomite limestone	29.9
203.0 - 203.2	limestone with clay	27.8
214.0 - 214.2	limestone	59.4
236.7 - 236.9	limestone	91.7
246.0 - 246.2	limestone	65.8

While drilling the following drilling parameters were observed:
- torque;
- crown loading;
- advancement speed.

Number of revolutions of drilling accessories was between 300 and 400 rev/min.

After calculating and optimizing drilling parameters we performed laboratory investigations by crown loadings cited in Table 2.

Table 2. Loading on drilling crown
Tabela 2. Obremenitve na vrtalno krono

Depth	**Rock type**	**Used loading on crown**	
[m]	**-**	**[kN]**	**[t]**
30.5 - 30.8	limestone	14	1.4
64.2 - 64.6	marl breccia	7	0.7
71.4 - 71.6	breccia with marl	10	1.0
98.0 - 98.6	marl dolomite	13	1.3
118.2 - 118.5	limestone breccia	15	1.5
124.3 - 124.6	dolomite marl breccia	13	1.3
130.1 - 130.5	dolomite breccia	12	1.2
134.0 - 134.3	dolomite breccia	16	1.6
142.0 - 142.4	dolomite	6	0.6
152.4 - 152.6	dolomite breccia	13	1.3
153.5 - 153.7	dolomite breccia	25	2.5
155.7 - 156.0	dolomite breccia	11	1.1
171.0 - 171.2	dolomite breccia	30	3.0
177.7 - 178.0	dolomite limestone	26	2.6
179.7 - 180.0	breccia dolomite	36	3.6
183.8 - 184.0	breccia dolomite	38	3.8
184.0 - 184.3	dolomite limestone	22	2.2
187.7 .- 188.0	dolomite breccia	38	3.8
192.4 - 192.6	dolomite breccia	41	4.1
193.5 - 193.7	breccia dolomite limestone	12	1.2
203.0 - 203.2	limestone clay	11	1.1
214.0 - 214.2	limestone	24	2.4
236.7 - 236.9	limestone	37	3.7
246.0 - 246.2	limestone	26	2.6

In tests diamond crown Ø 96/63.5 mm was used, double tube core barrel Ø 93 mm, drilling rods Ø 2 3/8" and drilling machine Fraste ML.

In spite the fact that geological list of core in particular segments shows same rocks for obtaining optimal advancement adaptations of crown loading were needed. The reason was the non-homogeneity of rock masses or non-homogeneity in particular rock as for instance cracks etc.

From determined loadings investigations for particular rock massifs we can give recommended optimal loadings as follows:

Table 3. Recommended optimal loading
Tabela 3. Priporočene optimalne obremenitve

Rock type	**Loading**	
	[kN]	**[t]**
dolomite	6	0.6
marl breccia	7	0.7
breccia with marl	10	1
limestone with clay	11	1.1
breccia dolomite limestone	12	1.2
dolomite breccia	12 – 41	1.2 – 4.1
marl dolomite	13	1.3
dolomite marl breccia	14	1.4
limestone	14.0 – 24.0	1.4 – 2.4
limestone breccia	15	1.5
dolomite limestone	23 - 26	2.3 – 2.6
breccia dolomite	36 – 38	3.6 – 3.8

CONCLUSION

Optimization methods of geo-mechanical – structural drilling is a complex procedure with no universal solution. Because of geo-mechanical and structural characteristics of rock massifs it is hard to forecast or predict drilling parameters needed to gain quality core. Great role in optimization plays experience and operator's knowledge of the device. Undoubtedly it is possible to give a report for optimal drilling method where we know expected geological rock structure that we shall investigate. Non-quality drilling works and savings at this point in practice means unsuitable projecting of pretentious surface and underground objects and many times increased investment costs.

POVZETKI

Optimizacija geomehansko strukturnega vrtanja z diamantnimi kronami

Metoda optimiranja geomehansko – strukturnega vrtanja je kompleksen postopek, ki nima univerzalne uniformne rešitve. Zaradi geomehanskih in strukturnih značilnosti hribinskih masivov, je težko natančno napovedati oziroma predpisati parametre vrtanja, ki so potrebni za pridobitev kvalitetnega jedra. Veliko vlogo pri optimiranju vrtalnih parametrov ima izkušenost in znanje operaterja vrtalne naprave. Nedvomno pa je mogoče podati priporočila za optimalen način vrtanja, kjer dobro poznamo predvideno geološko strukturo hribin, ki jih bomo raziskovali. Nekvalitetno opravljena vrtalna dela in varčevanje pri le-teh, pa v praksi pomeni neustrezno projektiranje zahtevnih površinskih in podzemnih objektov in mnogokrat veliko povečanje stroškov investicije.

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