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NEW SHAFT SINKING TECHNOLOGIES WITH LOW DEPTHS STRATA FREEZING

Summary. The mining and geological conditions of opening new hard coal deposits in Poland imply the necessity of employing special methods for more than 90 percent of the sunk shafts. Among the currently used methods the best developed is the freezing one incorporating two options, i.e.: frezing of the whole overburden or selective sectional freezing. Each of the procedures has been successfully employed when sinking shafts in Poland and abroad. At present a method for strata freezing to the depth of 760 m has been developed whereas the research and development establishments for mine construction are elaborating solutions for its application at the depth to 1000 m. The freezing method of shaft sinking has proved successful in extremely hard mining and geological conditions. Present efforts focus upon reducing the energy and time consumption.

1. INTRODUCTION

Hard coal mining in Poland covers recently three basins, i.e.: the Upper Silesian, Lower Silesian and Lublin-Chełm. Majority of mines (64) concentrate in the Upper Silesian Coal Basin, sharing 98% of the total coal output of the country. Before the year 2000 the structure will be a subject of minor changes only, due to the planned growth of production from two currently constructed mines in Lublin-Chełm Coal Basin. It is estimated that maintenance of the present production level requires construction of approximately 6000 m of new shafts a year, 30% of which is shared by deepened and inter-leval shafts. When opening deposits of the above mentioned basins it is required to pass the overburden of one to several hundreds meters thick, in most eases with the occurence of several water-bearing layers. The continuous process of mining out the existing coal resources requires opening of new, depper deposits which results in the worsening mining and geological conditions appearing as increasing pressure and temperature as well as gas hažard. The depth of new deppened shafts is about to exceed 1200 m. with high water content in the overburden-often highly mineralized and acting under high pressure. It is estimated that only 10% of the total shaft number will allow sinking by conventional methods throughout the shole length; the remaining part will require employment of special methods. Analysis of the present state of Polish shaft sinking technology points to the freezing method as one being the most popular among special methods. It has been applied for more than 30 years and improved over this time appear now as the most commonly employed for weak and flooded strata and high pressure conditions. The freezing depth reaches practically 760 m and efficiency of the method in such condition has been proved by several projects. At present it may be stated that from the theoretical and research point of view we are prepared to apply the freezing method for the depth of 1000 m.

2. SOME ASPECTS OF SHAFT SINKING TECHNOLOGY WITH ROCK FREEZING

Two principal directions of shaft sinking employing the freezing method may be distinguished in Polish mining construction:

- rock freezing throughout the whole overburdne,
- selective sectional freezing.

2.1. Shaft sinking in weak and flooded strata with freezing of the whole overburden to the depth of 760 m, in Lublin-Chełm Coal Basin

Strata freezing method is commonly applied in the world mining construction, however deep freezing, below 700 m is very rare. In Polish shaft construction, the method was used for several shafts of Lublin-Chełm Basin; the freezing depth ranged from 600 to 700 m. First shafts sunk in this region employed two phase freezing. During the first phase strata freezing reached the depth of 180 m to go down to the full depth of 720 m during the second phase. Such freezing method enabled early initation of sinking operations, however resulted in many difficulties in maintenance of the shaft lining, especially at the depth between 180 and 450 m. The occuring destruction throughout this section was the effect of active freezing and increase of the freezing mantle, also after constructing the lining. Maintaining the active freezing was needed at that time to obtain the required parameters of the conducting layer at the depth of approximately 590 m.

Considering the unsuccessful experience in two-phase freezing, sinking of next two shafts employed one-phase strata freezing over the depth from 0 to 760 m; the method is discussed below. The mining and geological conditions determined on the basis of borehole test data are listed on Fig.1. The hydrogeological conditions of the sunk shafts are presented in Table 1. In most layers water is not agressive for portland cement; it was only with in the depth range of 500-548 m and 584-750 m that week agressive leaching and sulphate performance occurred.

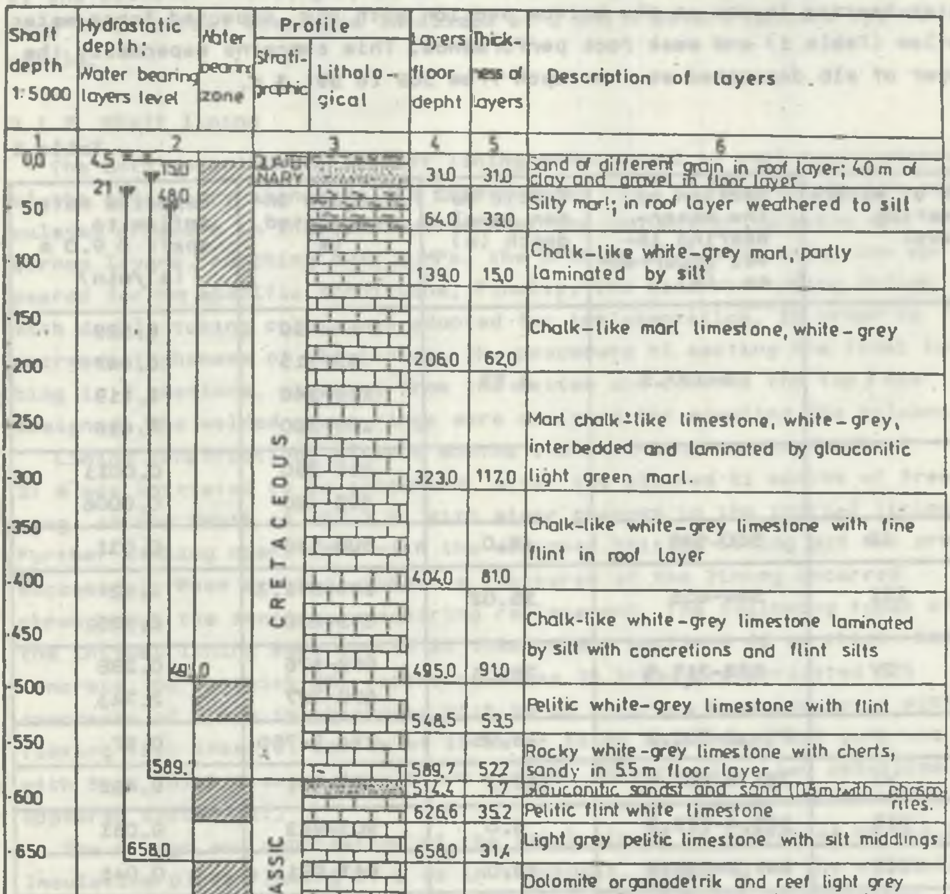

Fig. 1. Example of hydro-geological profile for shaft sinking with deep freezing

Rys. 1. Przykładowy profil hydrogeologiczny przy głębieniu szybu z zastosowaniem głębokiego mrożenia

2.1.1. Strata freezing

The applied strata freezing depth of 760 m is due to the occurrence of water-bearing layers at the bottom section with the expected large water inflow (Table 1) and weak rock performance. This concerns especially the layer of alb deposited at the depth from 589 to 591.3 m.

Table 1

No of water-bearing level	Section of the water-bearing level occurrence (m)	Static water level depth (m)	Section investigated (m)	Expected water inflow to shaft ϕ 9.0 m (m^3/min)
I	5-187.5	4.55	67- 90 92-115 118-140 169-200	0.529 0.047 0.119 0.010
			216-250 403-450	0.0011 0.0006
II	500-548	48.0	500-548	0.031
III	589-615	15.02	589-591.3 595-620	1.12 0.903
IV	658-715.9	78.05	652-676 699-727	0.286 2.743
V	734.2-750.2	78.05	734.2-750	0.37
VI	781.6-802.8	110.5	756-801	0.432
VII	903.4-929.8	6.0	903-943	0.061
VIII	949.2-958.9	50.0	943-991	0.041
IX	1071.5-1105	30.0	1071-1105	0.454

At this depth there occur dust sands of quicksand character as well as very weak jurassic rock reaching the depth below 715 m; their compressive strenght ranges between 1.5 and 4.0 MPa with the water inflow of 0.37 to 2.74 m^3/min. Rock with - in the first water-bearing level. to the depth of 187.5 m, is characterized by low strength.

Strata freezing was carried out through 45 boreholes over the ϕ 17 m circle (distance between boreholes was 1.1-1.2 m). The designed thickness of the freezing mantle of 6.5 m was calculated for the conducting layer quicksand deposited at the depth of 590 m, with the assumed strength (at 15°C) of 7.5 MPa.

In order to obtain the assumed thickness of the freezing mantle, freezing was continued for the period of 11 months by six units of 250 kW output each. The increase and maintenance of the freezing mantle was monitored by the accustic tests, geophysical measurements and temperature monitoring in 2 thermal boreholes localized at 2 and 3 meters outside the circle.

2.1.2. Shaft lining

The data describing the shaft lining constructed to meet requirements of the obligatory standards are presented on Fig. 2. Considering the calculated pressure in the alb layer and at the contact of jurassic and carbon layers, reaching over 9 MPa, the problem of lining selection appeared for the specific conditions. Finally, the concrete-tubing lining with double tubing column was adopted for implementation. In order to increase tightness of the lining, the procedure of setting the final tubing in 3 sections, starting from the bottom and towards the top, was designed. The welded picot rings were designed for coupling the columns.

Lining construction. After 5 months shaft sinking to the depth of 37 m was initiated to be continued, after the planned 11 months of freezing, to the depth of 197.7 m, with minor changes in the initial lining. Further sinking operations with the designed initial lining did not prove successful. When sinking, numerous fractures of the lining occurred through-out the sections, requiring replacement. The following types of the initial lining were tested at these shaft sections 40 cm thick: B15 concrete, 60 cm thick B25 concrete, class 35 brck, prefabricated B25 concreate of 0.4 m in thickness with 15 cm concrete trimming layer with flexing flat inserts, boards of 10 mm or 19 mm thickness, B25 concrete with 5 cm thick flexing insulation plates. Only the last two solutions appeared successful.

The design and application of the final lining is presented on Fig.2. Insulating plate flexing of 5 cm in thickness, anchored to the sidewalls over the whole surface was used at places of shaft crrb construction. It should be pointed out that despite considerable strata deformation towards the shaft centre no destruction of the freezing pipe occurred.

When sinking in the frozen section hand cutting was applied to be them replaced by a specially adopted heading machine. The last part of the frozen section was excavated by means of blasting.

The remaining shaft sinking operations did not differ principally from standard procedures.

2.2. Examples of sectional strata freezing

The cases of layers requiring freezing, occurring more frequently at greater depth stimulated the specialists to develop an efficient method for sectional freezing of strata. In Polish mining industry the method was successfully applied for several times as employed for both, horizontal and vertical operations. The most interesting examples include:

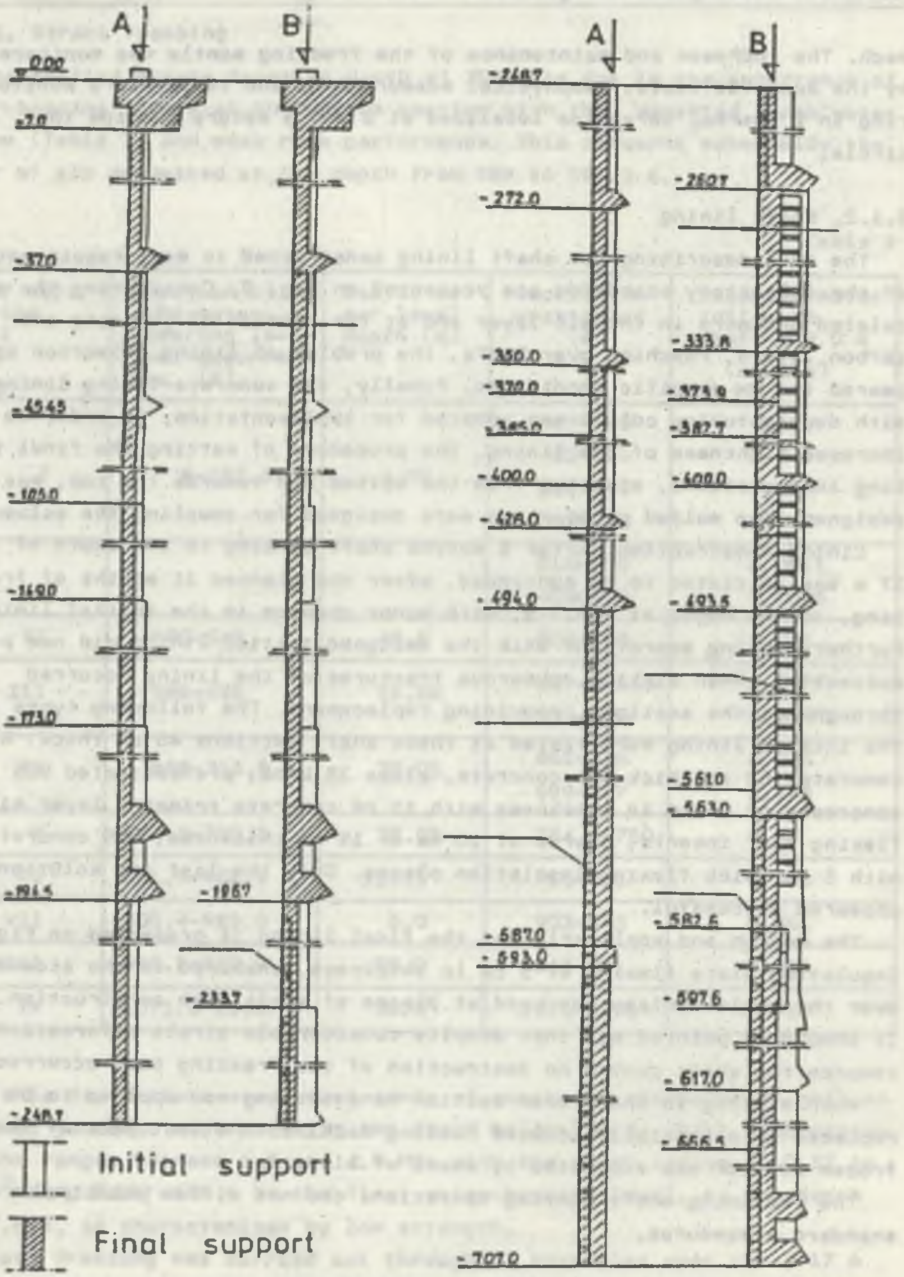

Fig. 2. Cross-section of the designed and constructed shaft lining to the 707 m level

A - lining designed, B - lining constructed

Rys. 2. Przekrój projektowanej i wykonanej obudowy szybu do poziomu 707 m

A - obudowa projektowana, B - obudowa wykonana

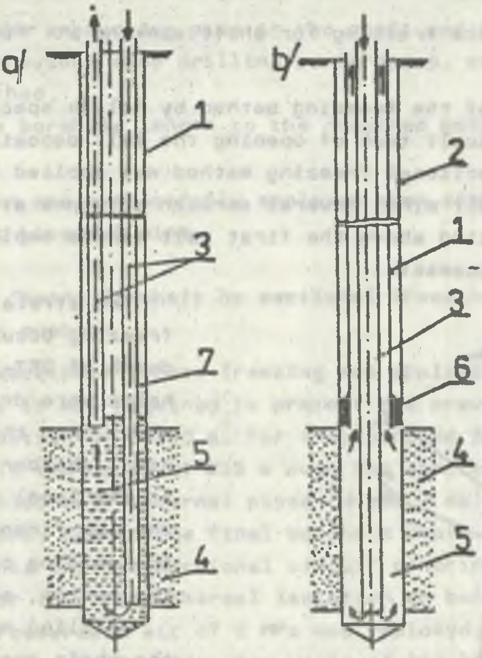

Fig. 3. Cross section of the freezing borehole for sectional freezing method

a - with air cushion and two columns of down-pipes, b - with triple column of pipes

1 - freezing pipe, 2 - casing pipe, 3 - down-pipe, 4 - frozen zone, 5 - brine, 6 - mechanical tightening, 7 - air cushion

Rys. 3. Schemat przekroju otworu mrożeniowego przy zastosowaniu metody odcinkowego zamrażania

a - z poduszką powietrzną i dwoma kolumnami rur opadowych, b - z podwójną kolumną rur

1 - rura mrożeniowa, 2 - rura osłonowa, 3 - rury opadowe, 4 - strefa mrożeniowa, 5 - solankę, 6 - uszczelniacz mechaniczny, 7 - poduszka powietrzna

- a shaft of "Tusanj" salt mine in Yugoslavia
- Zofiówka VI shaft "Manifest Lipcowy" mine
- Wapno I shaft in Żary
- 51/3 shaft in "Bogdanka" mine.

The quoted project employed two practical solutions. They were:

- sectional freezing with an air cushion and two columns of down-pipes sunk to different depth Fig. 3a.
- sectional freezing with a triple column of pipes localized coaxially. with mechanical barrier Fig. 3b.

2.2.1. Sectional strata freezing for shaft sinking at "Tusanj" mine in Yugoslavia

Good recognition of the freezing method by Polish specialistic allowed undertaking the difficult task of opening the salt deposit in Yugoslavia. In the sixties the sectional freezing method was applied for sinking two shafts at "Tusanj" salt mine. Several earlier attempts at passing the flooded strata deposited above the first salt series employing cementation did not prove successful.

Fig. 4. The system of drilling freezing boreholes from the shaft: sectional freezing of "Tusanj" shaft in Yugoslavia

1 - drilling chamber, 2 - conductor pipe, 3 - guiding pipe, 4 - buntons of the shaft reinforcement, 5 - freezing borehole, 6 - frozen zone

Rys. 4. Schemat układu wiercenia otworów mrożeniowych przez szyb - mrożenie odcinkowe szybu "Tusanj" w Jugosławii

1 - komora wierceń, 2 - rura prowadnicza, 3 - rura kierownicza, 4 - dźwigary zbrojenia szybowego, 5 - otwór mrożeniowy, 6 - strefa mrożona

The strata zone requiring freezing occurred at the depth of 257-330 m. The boreholes were drilled from the shaft. For this purpose a conical chamber was constructed at the level of 229 m above the low firmness rock Fig. 4: the guiding pipes were set at the bottom, at proper angle.

Drilling was performed from the shaft top through the column of conducting pipes, fixed every dozen or 50 meters in the shaft. After drilling the boreholes to the final depth of 330 m they were filled with cement wash; then the freezing pipes were sunk.

The constructed boreholes were connected to the separation rings mounted at the chamber bottom. The inflow and outflow of brine employed isolated pipelines fixed in the shaft. The obtained results indicate that the applied sectional freezing is one of the most efficient methods:

- the length of freezing boreholes is reduced down to the required minimum,
- no strata freezing is required, thus wastes are avoided,

- application of the conducting pipe in the shaft and the drilling unit on the surface provides easy drilling performance, comparable to the conventional method,
- reduction of the borehole length to the required minimum ensures drilling precision.

Similar solution was successfully employed when sinking Zofiówka VI shaft in "Manifest Lipcowy" mine.

2.2.2. Sinking of "Wapno I" shaft by sectional freezing method with an air cushion

The method of sectional strata freezing was applied also for sinking "Wapno I" shaft as it was required to protect the previously constructed lining over the section of 0-150 m. For this purpose 32 freezing boreholes were drilled to the depth of 215 m over the circle of 9.6 m in diameter. In the boreholes with external pipes (ϕ 139.7 mm) two columns of down-pipes were sunk; one to the final borehole depth - the second to the depth of 152 m. This ensured sectional circuit of brine at the depth of 152-215 m. In order to obtain thermal isolation in boreholes above the depth of 152 m, pressurized air of 2 MPa was emploeyd; it maintained brine at the required level. Two freezing units of 250 kW output were used.

2.2.3. Sectional freezing for sinking S1/3 shaft in Lublin-Chełm Coal Basin

After analysing various options of sectional freezing technology, it was initially decided to apply the air isolation method (Fig. 3). In this case it employed freezing boreholes of special construction drilled from the surface to the depth of 60.5 m. The boreholes were equipped with a column of ϕ 224 mm casing pipes; ϕ 139.7 mm freezing pipes and ϕ 63 mm down-pipes; a specially designed tightener was mounted at the depth of 575 m. Its operation resulted in the space between casing and freezing pipes being filled with air above its level and with brine beneath. it. Due to this, the intensive reception of heat occurred at the level 575--605 m to appear considerably lower over the remaining length of the borehole. The initial operation of boreholes proved the adopted assumptions, however after same time it was noticed that the space between pipies was filled with liquid.

As a consequence, the freezing zone increased to create possibility of destroying pipes by the freezing liquid. Under such circumstances a different solution for borehole reinforcement was employed. At the depth of 580-600 m the space between pipes was filled with cement was with 30-40% addition of magnetite dust improving the thermal conductive performance. Above the zone. the so-called "micro-spheres" (light fractions of fly ash) of good isolation properties were applied.

Moreover, the previously constructed shaft lining was protected by strata heating with hot water flowing through boreholes reaching the depth of 180 m (used for freezing of the upper zone) and by heating of the shaft tube with hot air to the depth of 576 m (Fig. 5).

Such solution resulted in the shape of the freezing mantle presented on Fig. 5.

In the layer of flooded alb (580-600 m) the mantle thickness reached 6.5-9.0 m to ensure safe shaft sinking; above the level the mantle was distant enough from the lining (with thickness reduced) not to create hazard of destroying the existing lining.

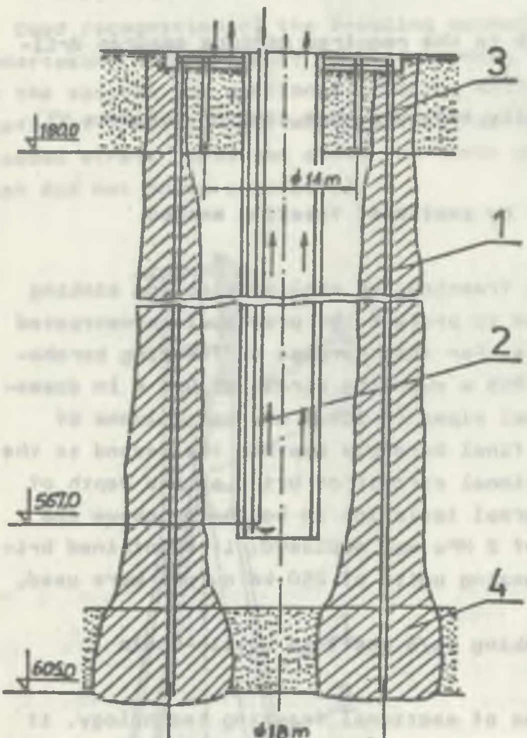

Fig. 5. Sectional freezing of S-1/3 shaft in Lublin Coal Basin

1 - freezing borehole, 2 - hot air inflow ducts, 3 - hot water outflows, 4 - freezing mantle

Rys. 5. Mrożenie odcinkowe w szybie S-1/3 w Zagłębiu Lubelskim

1 - otwór mrożeniowy, 2 - kanały dopływowe ciepłego powietrza, 3 - obieg gorącej wody, 4 - płaszcz mrożeniowy

3. SOME PROBLEMS OF SHAFT SINKING WITH FREEZING AT GREAT DEPTH

The presented above two options of the shaft sinking freezing method to the depth of 760 m may be generally considered as well-developed which does not obviously mean that they do not require further development. Analysis of the present stage of the technology indicate necessity of improving the following elements:

- design of the intensive freezing process;
- monitoring and control of the process;
- drilling and reinforcement techniques for frezzing boreholes;
- design and selection of the initial on the final lining;
- frozen rock cutting;
- strata defrosting and tightening of the lining.

Rapid and efficient strata freezing especially at great depth requires intensification of heat exchange between rock and brine of the freezing borehole; this requires consequently a "tribulent" flow. To achieve this pumps of respective parameters, resistive to the brine impact as well as equipping the unite with screw compressors are needed.

The existing Polish developments for monitoring the freezing process employ the thermal method as well as a geoacoustic one, based upon propagation of the acoustic wave in the selected pair of boreholes. Proper interpretation of data requires automatic recording of the monitoring data and employing the computer technology. This would result in the possibility of current control through the correction of brine flow rate in boreholes or through adjustment of the simultaneously operating units. In future, it is expected to employ radar techniques to monitor the increase of the freezing mantle. Further improvement is also needed in drilling techniques as well as borehole reinforcement, both drilled from the surface and from the shaft bottom. In the first case, apart from ensuring the vertical axis, proper reinforcement is required to provide limited freezing rate for sufficiently strong strata. In the second case (drilling from the shaft bottom), especially at great depth, it is required to improve drilling through conductor pipes from the surface or to design preventeres of minimal dimensions.

Shaft construction with strata freezing at great depth is a complex technological problem, especially in case of unstable and non-homogenous strata. In most of the shafts constructed under such conditions, minor or major lining destruction is being observed as resulting from the additional pressures due to the specific character of the freezing process, not considered when designing the project. Two basic sources of excessive strata deformation occur during freezing:

- strata stretching out as a result of freezing meet the resistance of its unfrozen part to produce considerable contact stresses;
- the mentioned increase of the freezing mantle deformation is multiplied when stretching out towards the shaft.

Bearing in mind the constantly growing freezing depth it is required to employ the shaft lining of special construction for both, the initial and final lining. The lining must appear as flexible (initial lining) extremaly tight and strong. The requirement are fulfilled by the integrated lining of separated construction. The flexible outer ring of steel-reinforced concrete initial lining takes the strata pressure whereas the internal, tight ring of the final lining protects against hydrostatic pressure. The design and employed materials of the initial and final lining are not perfect and require further development. The problem of stretching of particular rock types during freezing needs better qualitative and quantitative recognition; respective investigations are being carried out.

As indicated by the statistic 80% of rock at the frozen shaft sections is cut manually to avoid danger of destroying the freezing pipes. Recent experimence with heading machines points to this direction as one of the future. At present stage of development of Polish heading machine, cutting layers harder than 40 MPa appears as a problem.

The process of strata defrosting has not been well recognized yet. At present, intensive geoacoustical research as well as monitoring of thermal and strength parameters of the defrosted shafts is carried out. The observations and test data should enable forecasting in future of such phenomena as:

- sudden growth of pressure imposed upon the lining the to breaking of the freezing mantle;
- influence of structural changes in strata, due to freezing, on the lining load.

It is also required to improve the methods of tightening the lining under the sheath of a tight freezing mentle.

4. SUMMARY AND CONCLUSIONS

4.1. The geological and mining conditions of opening new hard coal deposits in Poland require, in 90% of cases, application of special shaft sinking methods.

4.2. The best developed Polish special method is the freezing one.

4.3. At present, Polish shaft construction establishments developed freezing methods for shaft sinking to the depth of 760 m; application of the method for the depth of 1000 m is being designed.

4.4. When employing the freezing method for sinking shafts at depth greater than 500 m it is most adventageous to apply selective sectional freezing of the chosen rock layers.

4.5. The freezing method of shaft sinking, consuming considerably much time and energy, proved successful in the most difficult conditions. In order to reduce operation costs it is required to improve certain elements of the process with special respect to the technology of drilling and reinforcement of freezing boreholes and control of heat exchange.

Rcenzent: Prof. dr hab. inż. Mirosław Chudek

Wpłynęło do Redakcji we wrzesniu 1987 r.

NOWE TECHNOLOGIE GŁĘBIENIA SZYBÓW Z ZASTOSOWANIEM MROŻENIA GÓROTOWRU DO DUŻEJ GŁĘBOKOŚCI

S t r e s z c z e n i e

Warunki górniczo-geologiczne udostępnienia złóż węgla kamiennego w Polsce narzucają konieczność stosowania w ponad dziewięćdziesięciu procentach głębionych szybów metod specjalnych. Ze stosowanych aktualnie metod specjalnych najlepiej opracowano metodę mrożeniową w dwóch odmianach, to jest: z mrożeniem całego nadkładu lub selektywnym mrożeniem odcinkowym. Każda z odmian została zastosowana z wynikiem pozytywnym przy głębieniu szybów na budowach krajowych i zagranicznych. Aktualnie opracowano metodę zamrażania górotworu do głębokości 760 m, a zaplecze badawczo-projektowe budownictwa górniczego przygotowuje warunki jej stosowania do 1000 m. Metoda mrożeniowa głębienia szybów została sprawdzona z wynikiem pozytywnym w szczególnie trudnych warunkach górniczo-geologicznych. Obecnie prowadzone są intensywne prace nad obniżeniem jej energo- i czasochłonności.

НОВЫЕ ТЕХНОЛОГИИ ПРОХОДКИ СТВОЛОВ С ПРИМЕНЕНИЕМ ЗАМОРАЖИВАНИЯ ГОРНОГО МАССИВА ДО БОЛЬШОЙ ГЛУБИНЫ

Р е з ю м е

Горные и геологические условия открытия новых пластов каменного угля ц Польше диктует необходимость применения специальных методов для более 90% шахт. Среди наиболее часто применяемых методов наиболее развитым является метод замораживания, который имеет два варианта: замораживание полной вскрыши или замораживание отдельных отрезков. Каждый из методов успешно применяется как в Польше, так и за границей. В настоящее время этот метод позволяет на замораживание глубины 760 метров, а исследования и развитие горных конструкций позволяет увеличить глубину замораживания до 1000 метров. Этот метод дал хорошие результаты в особо трудных горных и геологических условиях.

В настоящее время исследования ведутся в направлении уменьшения потребления энергии и времени.