Construction of Active Roadway Support Structure in Rock Characterised by Poor Load Bearing Capacity

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Abstract: In 1998 Premogovnik Velenje initiated an R&D project involving the modernisation of technology in relation to underground mine roadway support structures. The paper outlines procedures involved in the new method of roadway support construction using active roadway support. The new roadway support system is based on roofbolting. In the new roadway support structure, composite bolts are used in place of steel arch supports while timber lining is being replaced by nylon mesh. Rockbolts represent the central support structure element. At the Premogovnik Velenje coalmine, we have opted for so-called pre-stressed bolts, which have the capacity of bearing immediate loads and prevent convergence from developing. Consequently, we have made a detailed study of roofbolting as a process as well as of all the conditions, which may occur in the course of roadway support construction. To this end, we have carried out extensive geotechnical surveying in mine roadways where the new support structures have been installed, and applied the results to further work and development of underground mine structures and related technology. The new technological process also enables a continuous increase of load bearing capacity, from minimum values required to values substantially exceeding the load bearing capacity achieved by steel arch supports.

Izvleček: V letu 1998 smo pričeli z razvojno nalogo posodobitev tehnoloških del pri izdelavi podzemnih prostorov. V prispevku predstavljam dela, ki jih prinaša nov način podgrajevanja prog z aktivno podgradnjo. Nov podgradni sistem temelji na podgrajevanju s sidranjem. Sidra kot podgradni element nadomeščajo jekleno ločno podporje, lesen opaž pa nadomeščamo z armaturno mrežo iz umetnih materialov. Sidra v tehnološkem procesu predstavljajo osnovni podgrajevalni element. V Premogovniku Velenje smo se odločili za tako imenovana napeta sidra, ki imajo zmožnost prevzemanja takojšnjih obremenitev in ne dopuščajo razvoja konvergence. Zaradi tega smo sidranje kot proces podrobno proučili in obravnavali vse nastopajoče pogoje, ki se pri podgrajevanju lahko pojavijo. V ta namen smo izvedli obsežne geotehnične meritve, katerih rezultati so bili vodilo pri nadaljnjem delu in razvoju podgradnega sistema in tehnološkega procesa. Nov tehnološki proces omogoča zvezno večanje nosilnosti, od mivrednosti, ki močno presegajo dosežene nosilnosti jeklene ločne podgradnje.

Keywords: rockbolt, active support, insulation lining.
Ključne besede: Sidro, Aktivno podgrajevanje, Izolacijski plašč.

Short scientific paper

INTRODUCTION

An integral part of the process of coalmining is the construction of underground roadways used for ventilation, transport, connecting routes, exploration, preliminary works and excavation. The function of a particular roadway also determines the size of its cross-section, the design life and the type of roadway support structure used.

In the total length of various roadways constructed every year at the Velenje coalmine, in 85 % of cases steel arch supports in combination with insulation lining are used.

The analysis of the condition of roadway equipment and technology has shown that we have fallen behind in comparison with achievements in longwall excavation. The equipment as well as the technology, and the resulting rate of progress, result in massive costs of roadway construction. In the early times of roadway construction, roadheaders proved very useful mainly in cases of favourable conditions in the mine and comparatively small roadway cross-sections. The brunt of coal excavation, however, slowly shifted deeper underground, where working conditions were significantly poorer than in the Škale mine or in the eastern part of the Preloge mine. In addition, the development of longwall equipment and technology brought about a substantial increase in the volume of excavated coal, which in turn caused increased demand for air in the mine. To achieve normal ventilation of the mine, larger cross-sections of roadways were needed so as to enable the required rate of airflow. Bigger cross-sections were also necessary to enable the transport of mining plant and equipment of increasing sizes as well as the equipment for the removal of coal from high-productivity longwalls.

For that reason, Premogovnik Velenje decided to modernise the equipment as well as technology. With this goal in mind, a development project was initiated involving the modernization of tools, i.e. technological process in roadway construction. The objective of the long-term development of roadway construction has been determined by the following targets:

- Average rate of progress in roadway construction of 10 m/day,
- Development of efficient and effective roadway construction and support structures for cross-sections of up to 20 m^2,
- Investigate possible ways of roadway construction which would enable concurrent excavation (major phases) and support construction.

This, however, has necessitated the modernization of equipment, support elements, technology of support construction, as well as the entire technological process on roadway construction sites.

In terms of mine roadway support structure development, a new roadway support structure technology is being introduced, which is based on roofbolting. These roadways are used in the preparation of longwall roadways; consequently, they are only in use for short periods of time. The roadways enable the transport of excavated coal out of the mine and the delivery of material and equipment; they also provide ventilation and serve as walkways.

Development of Active Support Structure Elements

To eliminate unproductive phases of roadway support construction, use of metal support structures is being avoided as that approach precludes the continuity of the mining process.

Rockbolts are the central element in active support structure construction. To ensure adequate load bearing capacity and the balance between the support elements and the surrounding rock, a new technological procedure of roofbolting had to be developed, involving the tensioning of the installed bolt. In addition, bolts used should have adequate longitudinal load bearing capacity and significantly higher force at the nut than used to be the case in the past, in order to ensure load-bearing capacity at the time of installation of load bearing elements.

Development of rockbolt elements

In the new technological process, rockbolts are the central support structure element. For this reason, the majority of the time was devoted to the study of roofbolting technology, development and testing of individual elements of rockbolt support structure, and measuring the loads which occur in the course of active support structure construction i.e. roofbolting of mine roadways.

Bolt rod

Bolt rod is the basic load-bearing element in active support structures. The development of active support at the Premogovnik Velenje coalmine started with the advent of synthetic bolt rods, which could be installed by bracing.

Weidmann bolt K-60 is designed for the purpose of implementing support measures in the construction of new mine roadways. Weidmann bolt K-60 can be used as a support element in its own right; however, generally it is being installed as an additional support measure (in addition to arch supports and timber) in the construction of longwall roadways or to improve the support structure

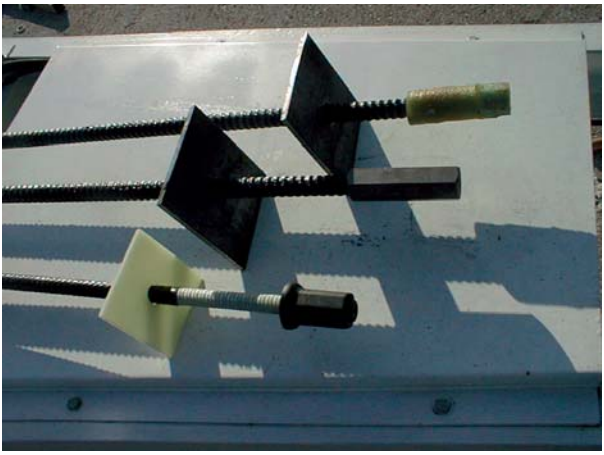

Figure 1. Weidmann bolts K-40 and K-60 complete with metal plate, metal nut and epoxy nut.

load bearing capacity in the construction of permanent mine roadways and in the fortification of already constructed mine roadways exposed to secondary stress state conditions.

The central element is the bolt rod, diameter 25 cm. The bolt rod may be of arbitrary length (the length of the rockbolt is specified by the design engineer). The maximum longitudinal force of the bolt rod is 380 kN with shear force resistance 120 kN. Another essential element is the bolt plate made of synthetic materials or metal, and the bolt nut, which may also be either metal or made of synthetic materials. Maximum load bearing capacity at the nut is 180 kN.

Laboratory testing of rockbolt elements

Prior to the implementation of roofbolt support, individual support structure elements as well as different types of bolts had to be subjected to detailed study and testing. In this context, the term 'bolt' is used to describe a single unit composed of the bolt rod, plate and bracing nut.

In addition to testing bolt tensile strength, bending and load bearing capacity at the nut, all types of bolts have also undergone torsion torque testing to determine maximum values achievable in bolt installation. Apart from laboratory tests, extensive testing of the quality of installation in the mine has also been carried out. These tests were used to determine cure times of adhesive cartridges, maximum bracing force for individual types of bolts, and the methods of bolt installation in the given natural-technological conditions. Finally, we extracted the bolts and determined the quality of bolt installation.

Development of the bolt nut from synthetic materials

Bolts made of synthetic materials which are installed by the tightening of the nut, generally share a common weakness i.e. their extremely poor load bearing capacity at the nut in comparison to other rockbolt elements. Generally, bolts of this type are used for bolt installation in solid rock where huge load bearing capacity at the nut is not required; where that requirement does arise, however, bolts with a metal nut are used.

In our case the required length of the bolt is comparatively short, however adequate force at the nut still needs to be provided. To this end, a nut made of synthetic material had to be developed. This type of bolt installation also required us to develop the appropriate plate.

For Weidmann bolts (Figure 1), we developed a prototype of a nut made of modern synthetic materials whose load bearing capacity at the same length exceeds that of a metal nut by more than 20 %. In 1998 this type of nut was used for testing purposes only, however in 1999 we started introducing it on a regular basis.

In addition to a new nut we also included an installation adapter, which enables adequate torque to be achieved in bolt installation. To prevent maximum torque from exceeding permissible values, we also designed a torque wrench, adjustable in the range determined by laboratory testing.

Development of roofbolting technology

Using Weidmann bolts, we started introducing the so-called active support structure where rockbolts are already prestressed at the time of installation. To determine the tensioning force i.e. torque, we developed certain tools which enable controlled rockbolt support installation.

Bolts can be installed in several different ways. The manner of bolt installation is determined in accordance with the purpose of bolt installation i.e. by support structure design requirements.

Irrespective of the manner of bolt installation, however, the drilling of a hole, which is 10-15 cm shorter than the length of the bolt rod, is required.

Geotechnical Surveying

Roofbolting as a process had to be studied in detail, and all the conditions potentially occurring in the course of roadway support construction had to be taken into account. We had to study the processes around the excavated roadway cross-section (in the coal seam) i.e. the stress state, the formation of the plastic zone and the diameter of the deformation zone in order to determine the required load bearing capacity and length of bolts extending through the deformation zone into the solid and elastic area suitable for bolt installation. The deformation zone may be determined by geotechnical surveying and study of the interpreted data[4]. The surveying was twofold: measuring the stress in the bolt and at the nut of the bolt, and measuring the ensuing deformation zone with electronic extensometers.

Surveying equipment

To determine useful bases for rockbolt support construction design i.e. to prevent the plastic zone from developing and to reduce the size of the deformation zone, surveyed cross-sections were designed so as to include all possible conditions occurring in the coal seam.

To this end, we had to measure the loads on the bolt rod under different conditions in the coal seam, the loads on bolt rods of different lengths and the loads at the nut of the prestressed bolt. In the course of extensive geomechanical surveying carried out for this purpose, the time progression of the deformation zone and the failure zone around the excavated cross-section of the roadway had to be determined under different conditions.

Measuring bolts and measuring plates at the nut

Measuring bolts are used for direct measuring of deformations, while the actual deformations, known bolt diameter and material elasticity module are used to calculate the forces (stress) which caused the deformations. To carry out the measurements, we used polyester Weidmann bolts fitted with a pair of strain gauges set 0.5 m apart[6] along the length of the bolt.

Generally, tensile deformations are small, with relative extensions and contractions of the order of 0.001 mm which makes direct measurements very difficult i.e. virtually impossible. Hence in practice, electrical resistance method (so-called 'strain gauge' method) is the method most frequently used. Here, the change in electrical resistance due to tensile deformation of the gauge wire is being measured.

Apart from strain gauges, bolts are also fitted with measuring plates at the nut for measuring the loads at the nut of the bolt.

To determine the stress in longwall roadways, bolts from 1.5 m to 3.5 m in length (increment 0.5 m) were selected. In this range, the bolt lengths most appropriate under different conditions i.e. in rock with different characteristics had to be determined, which necessitated the installation of a minimum of 6 such cross-sections surveyed (position in the coal seam from 0 to 1).

Electronic extensometer

Electronic extensometers are used for measuring displacements around the excavated cross-section of the roadway. As a rule, drill holes fitted with electronic extensometers are spread in a radial fashion resulting in a radial displacement of measuring points. Displacement measuring rings are spaced 0.5 m apart. The electronic extensometer allows the displacements to be determined with ± 0.001 mm accuracy. These measurements will help us to establish the deformation zone, in terms of time progression and in relation to the natural and technological conditions present, which forms during the excavation as well as after the completion of roadway support construction.

Implementation of geotechnical surveying

Before carrying out the surveying on the active support structure, parameters of the existing support system had to be determined in order to establish a credible basis for comparison. Subsequently, surveyed cross-sections were installed in the roadways featuring active support.

The selection of locations for geotechnical monitoring was based on physical-mechanical characteristics obtained for the engineering design of such structures using the 'classification of physical-mechanical characteristics'[3].

Results of geotechnical surveying

The results of the surveying have been collected in the geotechnical measurements database. For the most part, they are presented in graphical format, which makes it easier to detect changes as well as the causes of such changes. The presentation of results in graphical format is stored in the archives of the Hydrogeological Department of Premogovnik Velenje, and includes the diagrams of the measurements taken for each measuring element.

Both, the measurements as well as the technological process, were successfully implemented in the trial phase, confirming our theoretical assumptions.

SUPPORT STRUCTURE ANALYSIS AND MODEL FOR ENGINEERING DESIGN

Very roughly speaking, the phases involved in the technology of roadway construction in the Premogovnik Velenje mines can be divided in cross-section excavation and support structure installation. Unfortunately,

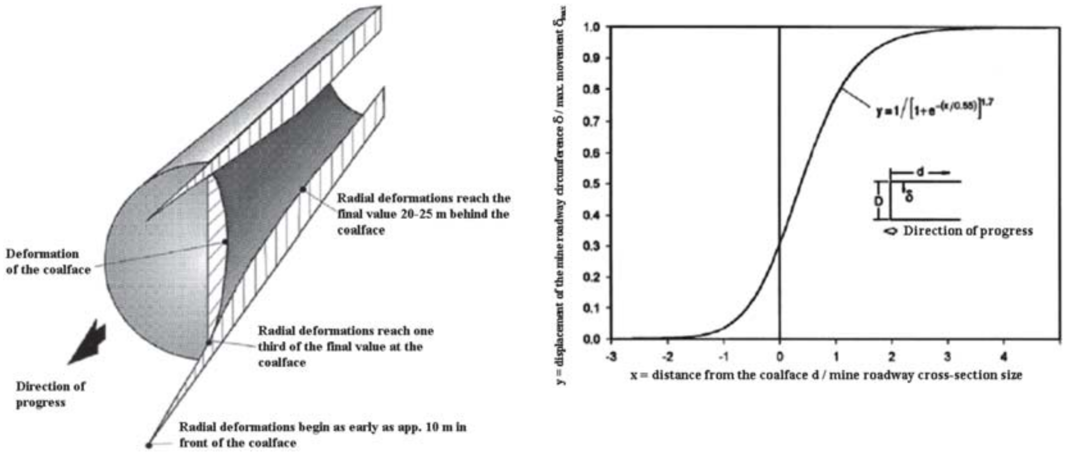

Figure 2. Deformations in relation to cross-section size and distance from the coalface.

the roadway cross-section shape and size, design life and type of support used differ according to the designated purpose of the individual mine roadway. The technological process of mine roadway construction and support used is determined by the characteristics of the surrounding rock. The equipment used in the process accounts for the greatest difference even though the purpose of individual stages is identical.

Therefore the analysis of the support structure and technology of roadway construction was carried out for the equipment most frequently used.

Support structure analysis

In the support structure analysis, a simulation of the roadway excavation and support structure construction was carried out using PHASE 2 software application. The analysis of support structure construction was modelled on the actual works carried out at the worksite. In Stage One, displacements of the finished roadway in relation to the size of its cross-section and distance from the coalface were analysed.

In the stages that followed, we analysed the support structure as constructed at the Premogovnik Velenje coalmine worksites. In the simulation, support was installed at 15 m, 10 m and 5 m behind the coalface, and in the final stage it was even put in immediately behind the excavation. In the last instance, the installed support structure was considered to have been constructed by means of bolts.

In fact, 10 bolts per linear meter of roadway at reduced density of steel arches account for more than 50 % of support required.

Roofbolting with CRAM drilling rig

In terms of past practice, roof bolting as a phase in the technological process represents an interruption of the technological process. The technological procedure differs from the traditional steel arch support only in the reduced density of steel arches; however, there is also an additional phase of setting-up drilling rigs, drilling of bolt holes and bolt installation. Efficient construction of active support requires the roadheader to be removed and a drilling rig to be set-up in each progress section. Consequently, prior to the analysis of these processes it frequently happened that roof bolting was being carried out behind the roadheader i.e. 10 – 15 m behind the coalface. Quite apart from the interruption of the technological process, the safety of workers became the next obstacle to bolt installation at the coalface.

This means that active support structure construction with CRAM drilling rigs (in case of smaller cross-section sizes) should be carried out in the following order:

- cutting of the cross-section,
- erection of reduced density steel arch supports and concurrent securing with wood,
- roof bolting of the coalface,
- active support structure construction,
- insulation lining and grouting 20-30 m behind the coalface.

Roofbolting of the coalface

In cutting the roadway cross-section, the coalface represents the largest open surface vulnerable to deformations (movement of the rock into hollow space). In the past, wooden bolts were used to secure the coalface by direct installation into the drill holes without adhesive. This prevented the collapse of large coal fragments bolted to the rock. However, this type of protection necessitated a large number of wooden bolts (20 to 30) to be installed in every section.

Since this was time consuming and comparatively ineffective, we started with active installation of composite bolts into the coalface. This prevented the rapid spread of deformations and ensured the stability of the coalface.

In the roof bolting of the coalface, 4 to 6 bolts are typically used. That quantity is sufficient to stop the rapid spread of deformations and prevent the coal from caving in. Following the implementation of active roof bolting of the coalface, the number of injuries sustained at the coalface has been reduced by half.

Roofbolting with GTA drilling platform

The GTA drilling platform enabled immediate bolt installation resulting in concurrent construction of support structure at the point of roadway excavation. The first diagram shows an almost ideal intersection of lines indicating the reaction of the rock and that of the installed support; the only problem is the deformation caused by the transient impact which occurs during the cutting of the roadway cross-section. In order to reduce the deformation zone to a minimum (which also implies shorter bolts), bolts should be installed immediately following the excavation of the cross-section.

We expected that bolt installation carried out directly after the cutting of the cross-section would result in improved conditions at the coalface (reduction in deformations) to the point where individual work phases could be performed concurrently rather than separately, which had been the case in the past (cutting of the entire cross-section followed by subsequent support structure construction). This would reduce the number of discrete work phases required. In bolt installation with drilling platform, the road-

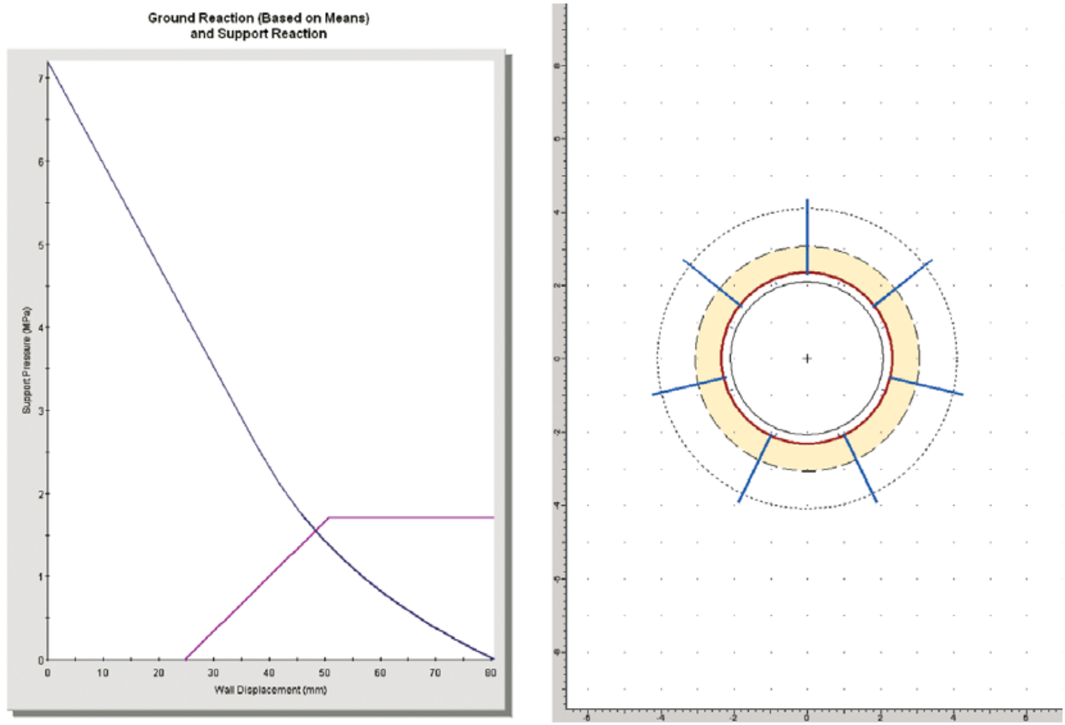

Figure 3. lt installation directly at the coalface.

header has to be removed each time and the platform brought to the coalface over the top of roadheader, which is very time consuming due to the size of the plant.

Occupational safety issues

When introducing changes to technological processes, the main issue in terms of workers' safety is to ensure the best possible working conditions at the coalface. We know for a fact that, in the past, most injuries in mine roadway construction were sustained as a result of coal collapsing from the coalface. In case of concurrent active support structure construction, this has been reduced mainly due to a greater stability of the coalface. Should the conditions at the coalface improve to the point where the cutting phase could be performed in a single step, this would decrease the number of times people have to stand directly under the coalface. Moreover, the introduction of a drilling platform also enables the roofbolting of the coalface, meaning that the coalface can be secured from a greater distance and from a different angle, consequently diminishing the risk of injury of this kind.

Support structure construction model

In 1996 we developed a model[2] for design engineering of mine roadways based on ten major factors with the most impact on the support structure.

The mine roadway design process at Premogovnik Velenje involves six steps, as follows:

1. Step 1: "Computer Model" Main Menu.
2. Step 2: Selection of the calculation for the entry of model parameters.
3. Step 3: Following the entry of the relevant parameters, the required support structure reactive pressure is calculated enabling the selection of the appropriate support.
4. Step 4: In Support Selection, the thickness of wood is selected as well as additional means of support used (types of bolts and density of bolt installation). The software automatically selects the types of steel arch supports whose load bearing capacity ranges from the required support structure reactive pressure to the selected value exceeding that load.
5. Step 5: In line with the designated purpose of the mine roadway, the shape and size of the cross-section are selected.
6. Step 6: For each cross-section the software calculates the estimated cost of construction of the roadway in relation to the chosen location (distance of transport of excavated coal and support structure materials), estimated rate of progress and several other parameters, which vary subject to the settings of the mine roadway construction costs management database.
7. In case of support systems being designed without resorting to the model, however, the software additionally enables the monitoring of impact of individual components of combinations of support systems on the load bearing capacity of the entire support system.

Just like the original, the improved model [5.DERVARIČ] also enables the selection of combined types of support. The user can select the distance between arch supports, longitudinal weight of arch supports, optional securing with wood and, of course, the type of the cross-section. The augmented version also includes roof bolting. Here, the user can select the type of bolt, type of bolt plate, density of bolts and bolt length. For each load bearing element involved in roof bolting, the model shows the result of the reactive pressure reached in total support, however only the lesser value is applied to bolts.

CONSTRUCTION OF A ROADWAY FEATURING ROCKBOLT SUPPORT

The purpose of constructing the middle roadway

At Premogovnik Velenje longwalls extremely high productivity has been achieved. However, high longwall productivity also results in a high level of dust and gasses released in coal seam collapse. To improve the climatic conditions at the longwall, the workplace environment group suggested that an additional roadway be constructed in the middle of the longwall. This roadway should be used primarily for ventilation purposes without actually interfering with the technological process of coalmining.

The middle, ventilation roadway should serve the following purposes:

- ventilation of exhaust mine gases in the excavation phase by way of the middle, ventilation roadway, where there are no workers present;

- reduce the rate of airflow at the longwall,
- elimination of coal dust by way of the middle, ventilation roadway.

Consequently, we decided to build the middle, ventilation roadway for longwall aeration using active support. The technological process of active rockbolt support construction also enables a continuous increase of load bearing capacity, from minimum values required to values substantially exceeding the load bearing capacity achieved by steel arch supports. This is a huge advantage, should the trend of increasing roadway cross-section sizes in the Premogovnik Velenje mines continue.

Subject to timely and proper implementation, active rockbolt support construction minimizes the deformation zone around the finished roadway, which also results in improved fire safety i.e. only minimal protective lining is required with load bearing capacity limited to ensuring the protection of the lining itself and that of the protective mesh made of synthetic materials used in place of timber lining.

The results have proven the specific usefulness of active support installations, particularly as follows:

- Cheaper roadway support structure construction.
- Cheaper construction of the fireproof lining.
- Less transport involved in assembling and disassembling i.e. in arch construction.
- Faster progress of longwall excavation due to fewer slowdowns in arch disassembling.

The objective in roadway construction is for the roadway support structure to be made exclusively of bolts and non-metal support elements (lining). Another objective was to mine all the coal found in the course of construction of the middle roadway.

Location of the pilot project and physical-mechanical characteristics of coal

The location selected for the trial construction of a middle, ventilation roadway was Longwall k. –90 B in Preloge mine. The roadway was being constructed from the face limit in the direction of longwall excavation. The objective in roadway construction is for the roadway support structure to be made exclusively of bolts and non-metal support elements (lining).

The physical and mechanical parameters[3] indicate the conditions at the proposed location of the middle, ventilation roadway to be very good. The roadway is situated in an area where the levels of stress caused by excavation are highest, which, in case of extremely fractured geological structure of coal, can present problems in ensuring the stability of the roadway at the coalface.

Construction of the exhaust air roadway support structure in the middle of Longwall k. –90 B

The following parameters were used in the calculation of the required reactive pressure of the support structure:

In case of above parameters, a 203 kPa support structure is required. However, due

Table 1. Parameters for the calculation of reactive pressure.

Convergence	2 %
Design life	100 days
Position in the coal seam	0.34
Uniaxial compression strength	9 MPa
Cross-section size	11.93 m^2 (KP1)
Distance from the old works	25 m
Distance from the existing roadway	20 m
Distance from active longwalls	1 m
Distance from the coalface	1 m
Rate of construction	3 m/day
Conditions	Poor
Fault presence	Yes

to the roadway being situated in the area subject to a direct impact of the longwall, causing the stress to increase by an additional 80 % (as indicated by past surveying), the roadway would be designed to a 400 kPa support structure[1].

While steel arch supports were used in the actual construction of the roadway, they were not included in the calculations therefore the required load bearing capacity has been calculated for rockbolt support only.

In the calculation, the following values have been applied: maximum load bearing capacity at the nut 170 kN, load bearing capacity of the bolt rod 300 kN and length of section 1.5 m.

$$\frac{n \cdot 0.95 \cdot F_s}{d \cdot O} = \sigma \qquad (1)$$

n - number of bolts
F_s - maximum longitudinal force of the bolt rod
d - distance between steel arch supports
O - circumference of the roadway cross-section
σ - load bearing capacity achieved

Given the progress of excavation (section length 1.5 m), the number of bolts required is 26 with bolt length 2.5 m.

All bolts are installed by means of adhesive cartridges i.e. one 30-second cartridge (bottom of the drill hole) and four 4-minute cartridges.

Technology of mine roadway construction

The technological process applied was designed to closely follow the previously used method of roadway construction. We decided on round-shaped cross-section KP1, diameter 4 m. The cutting of the cross-section was carried out by a GPK roadheader. Section length (increment) was 1.5 m. In each section (increment) one frame of steel arch support structure (without ground arches) was erected (steel arch supports were entirely removed upon completion). As a rule, the cutting of the cross-section was a two-stage operation; in certain cases, when conditions were good, the entire cross-section was cut in a single step.

The cutting of the cross-section was followed by the erection of steel arch supports. With steel arch supports in place (entirely or in the individual stage of the process), protective mesh lined with coconut fibres was installed. In installing the protective mesh we used pit props that were removed once the roofbolting had been completed.

The installation of the protective mesh was followed by roofbolting. Roofbolting was carried out as shown in Figure 12. Since each section (increment) required 26 bolts to be installed, the bolts have been distributed uniformly along the entire circumference, in two rings. The distance between individual bolts along the circumference is app. 1 m with the rings spaced 0.75 m apart.

The drilling of the 2.4 m long bolt holes measuring 32 mm in diameter was carried out by two CRAM drilling rigs as well as by manual drills. Manual drills were used in the installation of bolts into the roadway floor. Bolt installation was performed with three adhesive cartridges i.e. a quick-setting cartridge (30 seconds) placed at the bottom of the drill hole followed by two 4-minute adhesive cartridges. The bolt was installed by being rotated first (at app. 100 rev/min) until the first quick-setting adhesive cartridge had been activated, and then the nut was tightened into position by applying the torque of 110 Nm (torque wrench setting).

In the installation of bolts we also used 1.25 m long wooden clogs, into which Ø40 mm holes had been drilled at 0.75 m intervals. Under the drill holes, the wooden clogs were lined with wooden plates.

The main function of the wooden clogs was to secure the mesh to the rock and minimize the number of pockets in case of crushed coal. The plates fitted to the wooden clogs enabled uniform distribution of the injected grout along the entire circumference of the track in addition to sealing the holes drilled in the process of roofbolting.

Installation of protective lining

When using protective mesh in the past, we would typically experience a number of problems with pockets forming as a result of the coal collapsing along the circumference of the mine roadway, as well as difficulties in the application of insulation plaster. For this reason we opted for protective mesh lined with coconut fibres. Coconut fibres initially made the protective mesh somewhat stiffer; in addition, they are also permeable to liquids although some liquid is retained in the pores between the fibres. By installing this type of protective mesh we avoided the application of insulation plaster i.e. we only had to carry out injection grouting behind the mesh. The injected grout impregnated the coconut fibres thereby additionally stiffening the lining. Initially, however, this type of lining enabled the drainage of any surplus water not required in the hydration process.

Due to the modified technology of installation of insulation lining, coal oxidation processes were being closely monitored. The monitoring was done by means of a manual infrared camera Argus P 4438 EEV. Control measurements were performed on a weekly basis for the duration of roadway construction. In this regard it ought to be noted that no heating of the coal was recorded at any stage, either during the construction of the roadway or later in the course of coalmining.

Geotechnical monitoring

The design as well as the quality of installation of the support structure was the subject of ongoing geotechnical monitoring. Geotechnical surveying was carried out using already proven surveying equipment. Three 2.5 m long measuring bolts, respectively, were installed in both sides as well as in the roof of a section of the roadway. The surveyed cross-sections fitted with measuring bolts were located at the start (face limit), at the 25 m station and 50 m from the face limit. The last surveyed cross-section was 2 m from the coalface where the trial section ended. Bolts had also been fitted with measuring plates for measuring the loads at the nut of the bolt.

Measurements on the bolts were taken for three successive days from the day of installation, and twice a week after that. The frequency again increased (every day) when the longwall approached the coalface by less than 100 m.

The second part of the surveying was done by electronic extensometer. Location-wise, extensometric surveying was performed at the same locations as the surveying with measuring bolts. Extensometric surveying was carried out in the roof and in both sides at the depth of 5 m. Measurements were taken on a daily basis i.e. when displacements were of the order of 0.1 mm/day (and twice a week after that, but only when the coalface was more than 100 m away). Apart from measuring displacements in the rock, we also monitored the displacements along the circumference of the track by classic three-point measuring of convergence using a slide-rule. Convergence cross-sections were 5 m away from extensiometric cross-sections.

Results of geotechnical monitoring

In the course of roadway construction, as well as after the roadway had been completed, exceptional results were recorded. All parameters monitored were within the limits ensuring a stable roadway featuring a sound support structure.

Displacements along the extensometer drill holes did not indicate any collapse deep in the rock; on the contrary, the maximum measured depth of several major displacements, which could come close to plastic deformation, occurred at the depth of 1 m, which is within tolerance for this type of support.

In the course of convergence monitoring, the biggest readings were recorded at the end of the longwall pillar (at the start of the construction of the roadway). That part of the track featured bolts as well as steel arch supports. The deformations measured on the remaining surveyed cross-sections were extremely small. It is interesting that the biggest deformations measured occurred along the vertical axis.

When analysing the results of the load on the measuring bolts, it can be easily spotted that after the initial, almost linear increase, the loads quickly settled at the values ensuring considerable safety.

Excavation of the middle roadway

The promising results of geotechnical monitoring while approaching the longwall led us to believe that breaking through the rock between the longwall and the roadway would be successful, and consequently we did not expect to encounter major problems in excavation.

The operation was indeed a success and resulted in exceptional climatic conditions at the longwall once double wing ventilation had been established.

During construction and excavation we were monitoring several parameters – indicators of climatic conditions at the longwall. In addition, we were also monitoring individual work operations, stability of the middle roadway, concentrations of CO_2 and CH_4 in the exhaust air, particulate saturation of exhaust air and other factors.

Results of condition monitoring at the longwall and in the middle roadway

In the course of bringing the longwall to the middle roadway, no major displacements or damage to the support system in the middle roadway became apparent. At the time of breaking through the rock into the middle roadway, there were already advanced deformations present in the middle roadway, in the length of 3 m to 4 m from the mouth of the middle roadway (primarily in the roof). Around the mouth of the middle roadway, pockets had formed. In some cases, the coconut mesh lining gave way, causing pieces of coal to break off the roof and fall onto the track.

The coal seam in the middle roadway was becoming increasingly fractured. During individual work operations (cutting, advancing), in places coal would collapse to the extent where air could no longer be ventilated through the middle roadway. Consequently, to ensure double wing ventilation, additional support measures had to be implemented.

Conclusion

In 1998, the team charged with construction of support structures started working on an R&D project involving the modernisation of technology in relation to underground mine roadway construction. In the very first year we started developing and implementing a new support system based on roofbolting, i.e. a combination of steel arch supports and wooden or mesh lining.

In the new technological process, bolts were used as the primary support element rather than playing merely a secondary role in the support structure.

To determine the best materials to be used in active support structure construction, extensive laboratory research and testing was carried out. Initially, rockbolt elements were tested to verify the results reported by the manufacturer; later on, testing served to provide the data on the newly developed elements that we had adapted for use in the coalmine or designed specifically for the purpose. Apart from basic tests, we also tested the key parameters involved in machine installation of the bolts.

In addition to testing bolt tensile strength, bending and load bearing capacity at the nut, all types of bolts were subjected to torsion torque testing to determine maximum values achievable in bolt installation. Torsion, in particular, presented a big problem in the initial stages of the application of quick-setting adhesive cartridges, due to the bolt rod being overloaded at the nut of the bolt. The torque of the equipment used in bolt installation significantly exceeded the maximum torsion load of bolt rods, which resulted in coal failure even as the bolts were being installed. To solve this problem, we developed a torque wrench i.e. an adapter determining the maximum torque for bolt installation as such a tool was not available on the market.

Bolts made of synthetic materials, which are installed by the tightening of the nut, generally share a common weakness i.e. their extremely poor load-bearing capacity at the nut in comparison to other rockbolt elements. In our case the required length of the bolt is comparatively short, however adequate force at the nut still needs to be provided. For this reason, we developed a nut made of modern synthetic materials whose load-bearing capacity at the same length exceeds that of a metal nut by more than 20 %.

Apart from laboratory tests, extensive testing of the quality of installation in the mine was also carried out. Those tests were used to determine cure times of adhesive cartridges, maximum bracing force for individual types of bolts, and the methods of bolt installation in the given natural-technological conditions. Finally, we extracted the bolts and determined the quality of bolt installation.

A great deal of work was involved in relation to the protective lining used in active support. To prevent oxidation processes, protect workers and ensure the appropriate shape and load bearing capacity of the constructed mine roadway, we had to develop the type of lining that would become sufficiently stable in a short period of time, allow for local deformations which do not affect the entire support, and lend itself to fast and simple installation.

The best results were obtained with the lining made of protective mesh lined with coconut fibres. Coconut fibres initially made the protective mesh somewhat stiffer; in addition, they are also permeable to liquids although some liquid is retained in the pores between the fibres. By installing this type of protective mesh we primarily avoided the application of insulation plaster, i.e. we only had to carry out injection grouting behind the mesh. The injected grout impregnated the coconut fibres thereby additionally stiffening the lining. Initially, however, this type of lining enabled the drainage of any surplus water not required in the hydration process.

Roofbolting as a process had to be studied in detail, and all the conditions potentially occurring in the course of roadway support construction had to be taken into account. The surveying was twofold: measuring the stress in the bolt and at the nut of the bolt, and measuring the ensuing deformation zone with electronic extensometers. In the course of extensive geomechanical surveying carried out for this purpose, the time progression of the deformation zone and the failure zone around the excavated cross-section of the roadway had to be determined under different conditions.

Since this was time consuming and comparatively ineffective, we started with active installation of composite bolts into the coalface. This prevented the rapid spread of deformations and ensured the stability of the coalface. In the roofbolting of the coalface, 4 to 6 bolts are typically used. That quantity is sufficient to stop the rapid spread of deformations and prevent the coal from caving in. Following the implementation of active roofbolting of the coalface, the number of injuries sustained at the coalface has been reduced by half.

By analysing the support structure construction i.e. the technology of support processes, we identified the most appropriate technological process as well as its weaknesses. We also highlighted the changes required in logistics so as to improve the flow and consistency of operations.

The improved model of roadway support structure construction also enables the selection of combined types of support. The user can select the distance between arch supports, longitudinal weight of arch supports, optional securing with wood and, of course, the type of the cross-section. The augmented version also includes roofbolting. Here, the user can select the type of bolt, type of bolt plate, density of bolts and bolt length. For each load bearing element involved in roofbolting, the model shows the result of the reactive load reached in total support, however only the lesser value is applied to bolts.

The new type of support requires less hard labour (handling of steel arch supports and thick wood panelling). In addition, the transport required is also reduced. Active support structure elements are much lighter, take up less room and do not need to be constructed. Active support offers a huge advantage in actual excavation, as the unproductive work phase of constructing the steel arch support is significantly reduced and eventually even eliminated.

The technological process of roofbolting also enables a continuous increase of load bearing capacity, from minimum values required to values substantially exceeding the load bearing capacity achieved by steel arch supports. This is a huge advantage, should the trend of increasing roadway cross-section sizes in the Premogovnik Velenje mines continue.

Subject to timely and proper implementation, the technological process should minimize the plastic zone around the finished roadway, which should also result in improved fire safety.

The research in relation to active support should by all means be continued due to significant advantages inherent in this type of support structures, which makes them really hard to overlook.

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