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EVALUATION AND DESIGN OF OPTIMUM SUPPORT SYSTEMS IN SOUTH AFRICAN COLLIERIES USING THE PROBABILISTIC DESIGN APPROACH

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Abstract

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This thesis addresses the problem of designing roof support systems in coal mines. When designing the roof support, it is necessary to account for the uncertainties that are inherently exist within the rock mass and support elements. The performance of a support system is affected by these uncertainties, which are not taken into account in the current design methodologies used in South Africa. This study sets out to develop a method which takes all uncertainties into account and quantitatively provides a risk-based design.

Despite the fact that the roof bolting is probably one of the most researched aspects of coal mine ground control, falls of ground still remain the single major cause of fatalities and injuries in South African collieries. Mainly five different support design methodologies have been used; namely, analytical modelling, numerical modelling, physical modelling, design based on geotechnical rating systems and field testing. As part of this study, it is shown that there are many elements of a support system that can impact the support and roof behaviour in a coal mine and the characteristics of these elements as well as the interaction between them is complex and can vary significantly within a short distance. These variations account for uncertainties in coal mine roof support and they are usually not taken into account in the above design methodologies resulting in falls of ground and/or over design of support systems.

The roof and support behaviour were monitored at 29 sites at five collieries. It is found that there was no evidence of a dramatic increase in the stable elevations as experienced in some overseas collieries. A roadway widening experiment was carried out to establish the critical roof displacements. The maximum width attained was 12 m at which stage 5 mm displacement was measured. During the monitoring period no roof falls occurred at any of the 29 sites and road

widening experiment site, even where 12 mm displacements were measured. The in situ monitoring programme was continued in additional 26 monitoring stations in 13 sites with the aim of establishing the effect of unsupported cut-out distance on roof and support performances. The results showed that the lithological composition of the roof strata plays a major role in the amount of deflection that was recorded. Bedding separation was seen to occur at the contacts between different strata types. It is concluded that the roof behaved like a set of composite beams with different characteristics. It is also found that the amounts of deflection corresponded with the deflection that would be expected from gravity loaded beams. During this monitoring programme variable nature of roof and support systems are also demonstrated.

As many mines use different geotechnical rating systems, an evaluation of the currently used classification techniques were conducted to determine their effectiveness in design of roof support strategies. It is found that currently used systems cannot quantitatively determine the required support system in a given geotechnical environment. Impact splitting tests are found to be the appropriate system for South African conditions. It is however concluded that the roof lithology, stress regime and roof characteristics can change within meters in a production section. Therefore, in order to predict these changing conditions many boreholes are required for a section, which would be costly and time consuming.

An in-depth study into the roof support elements was conducted for the purpose of obtaining an understanding of the fundamental mechanisms of roof support systems and developing guidelines for their improvement. All of the currently available roof bolt support elements and related machinery were evaluated using *in situ* short encapsulated pull tests. The results showed that, on average, bond strengths obtained from the roof bolts supplied by different manufacturers can vary as much as 28 per cent. The test results conducted on different resins showed that the strength of resin currently being used in South Africa is adequate. Differences between commonly used bit types were established. It is concluded that the 2-prong bit outperforms the spade bit in sandstone and shale rock types. In addition, the effect of hole annulus was also investigated as part of this study. The results show that an annulus between 2.5 mm to 3.8 mm resulted in the most effective bond strengths. The effect of wet and dry drilling was noted. It is found that bond strengths and overall support stiffnesses are greater with the use of the wet drilling in all resin types. The results from the tests in different rock types highlighted the very distinct differences between bolt system performances. Quality control procedures for compliance with the design, support elements and quality of installation are presented. Recommendations for improving the quality control measures and for developing testing procedures for bolt system components, installation quality and resin performance are provided.

Finally, a roof support design methodology that takes into account all natural variations exist within the rock mass and the mining process has been developed and presented. This was achieved by adapting a probabilistic design approach using the well established stochastic modelling technique. This methodology enables rock engineers to design roof support systems with greater confidence and should result in safer and economic extraction of coal reserves.

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Glossary

Abbreviations

2D	two dimensional
3D	three dimensional
BTS	Brazilian Tensile Strength
CM	continuous miner
CMRR	coal mine roof rating
D&B	drill and blast
DME	Department of Minerals and Energy
FOG	fall of ground
GP	grip factor
IST	impact split test
ISR	impact splitting unit rating
PoF	probability of failure
PoF	probability of stability
RMR	rock mass rating
RQD	rock quality designation, usually determined by accumulating all pieces of core greater than 100 mm in a borehole and expressing the value as a percentage of the length of hole or portion of the hole
SM	safety margin
UCS	uniaxial compressive strength
UTS	ultimate tensile strength

Symbols and technical terms

ρ	the density of rock
μ	coefficient of friction between the layers
τ_{max}	maximum shear stress

σ_1	in rock testing, commonly the axial stress
σ_1, σ_2 and σ_3	major, intermediate and minor principal stress
σ_{xx}	maximum tensile stress
σ_3	in rock testing, commonly the confining stress
β	reliability index
η_{max}	maximum deflection
τ	contact shear strength
abutment	the solid area at the edge of a mined out area
bord	roadway driven in orebody or seam and specially defined as that area between two pillars, which is not included in the definition of an intersection
B	bord width
B_S	bond strength
core	cylindrical shaped rock retrieved from a borehole
D	nominal diameter of the anchor or borehole
d	distance between the rows of roof bolts
density	mass per unit volume
discontinuity	geological or mining induced breaks in the rock mass
E	elastic modulus
extensometer	measures deformation within the rock mass by means of anchors placed within a borehole
extraction ratio	the ratio of mined to unmined ground
face	the end of a panel which is advanced during mining
floor	the rock mass below the excavation
fracturing	discontinuities forming as a result of mining
g	gravitational acceleration (9.81 m/sn^2)
geomechanical testing	test to determine the physical properties of a geological material
geotechnical condition	an evaluation of the nature and condition of the geological discontinuities and rock material contained in a rock mass
$G(X)$	performance function

h	mining height
h_1	height of roof softening
intersection	The area where two roadways meet or cross one another
ISRM standards	international standards for rock mechanics tests set by the International Society of Rock Mechanics
joint	geological discontinuity
k-ratio	the ratio between the horizontal and vertical stress
L	span
L_b	distance between the bolts
l_b	bond length
n	number of bolts per square meter
N_{mc}	number of Monte Carlo trials
panel	span between the barrier pillars
panel span	the mined out span between two adjacent lines of barrier pillars or abutments
phi (ϕ)	friction angle
point anchor	a roof bolt anchoring system where the anchor is in contact with the strata for a relatively short distance.
Poisson's ratio	lateral strain divided by axial strain, lateral strain being the result of an axial stress
roadway	an excavation developed in a coal seam, which encompasses both a bord and an intersection
roof	the rock mass above the excavation
roof bolt	a steel tendon anchored chemically (resin) or mechanically complete with a nut washer and meeting performance specifications
SF_{sus}	safety factor in suspension mechanism
SF_{beam}	safety factor in beam building mechanism
SF_{slide}	roof bolt sliding safety factor
S_B	ultimate tensile strength of a bolt

spalling	slabs that develop as a result of stress or time
span	the shortest distance between in-panel pillars or faces
tensile stress	normal stress tending to lengthen a body along the direction in which it acts
t_{com}	competent layer thickness
t_{lam}	laminated lower strata thickness
T_R	frictional shear resistance of tensioned roof bolts
T_B	shear resistance generated by the bolts
tensile zone	a tensile stress field that develops above a panel as a result of mining
unit weight	the weight per unit volume.
V	shear force
V_{max}	maximum shear force
Young's modulus (E)	stress divided by the strain resulting from the stress