THE INFLUENCE OF ROOF BOLTS LOCATION ON ITS INTERACTION WITH THE ROCK MASS.

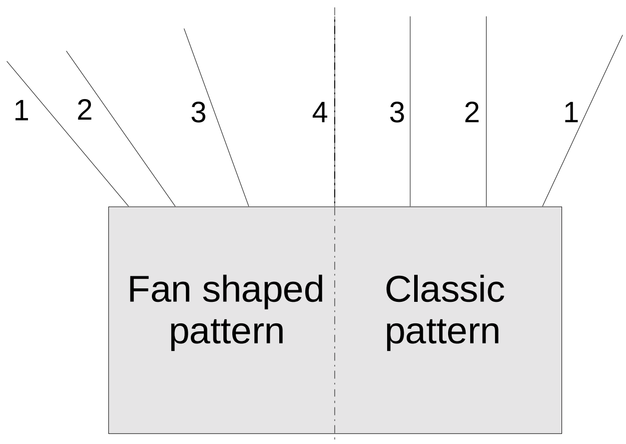
M. Cała[1], A. Tajduś[1]

ABSTRACT

This paper examines the influence of roof bolts location on its interaction with rock mass in the vicinity of an opening. Two patterns of roof bolting were analysed, first 'classic' assuming bolting perpendicularly to lamination with equal spacing between bolts, and second 'fan shaped', assuming inclination of all bolts (except the central bolt) and non-uniform spacing. The non-uniform spacing results from the distribution of shear forces. The inclination of roof bolts results from the distribution of the maximum principal stress trajectories. In order to investigate the interaction of bolts with the laminar rock mass for both patterns several numerical models utilising the code FLAC were calculated. Finally, it may be stated that for some types of laminar rock mass fan-shaped pattern may be favourable (unless the yield force limit in the bolt is not exceeded). For some others types classic way of roof bolting is preferred. Detailed consideration of all calculated numerical models leads to the conclusion that interaction of bolts with the rock mass depends not only on the mechanical properties of roof layer. We have to take under consideration mechanical properties and geology of all strata in the vicinity of an opening.

INTRODUCTION

The main aim of rock bolting is to reinforce such regions of rock mass where tensile and shearing stresses might cause dilation and/or shearing displacements dangerous for the stability of an underground opening. The roof bolts in the rectangular underground openings are usually installed perpendicularly to lamination with equal spacing. This paper examines the influence of roof bolts location on its interaction with rock mass in the vicinity of an opening. Two cases of roof bolting were analysed (fig.1). First, 'classic pattern' assuming bolting perpendicularly to lamination with equal spacing between bolts and second, assuming inclination of all bolts (except the central bolt) and non-uniform spacing 'fan shaped pattern'.



The non-uniform spacing results from the distribution of shear forces (Gałczyński, 1973; Peng, 1986; Cała, 1997). The advantages of non-uniform spacing of the bolts were studied by model experiments (Dunham, 1976) and also observed in the field (Snyder, 1984; Jeffrey & Daemen, 1984 and Stimpson, 1984).

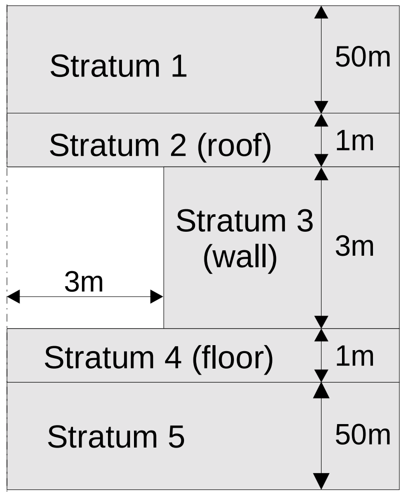
The inclination of roof bolts results from the distribution of the maximum principal stress trajectories. This way of reinforcement is similar to the concept of concrete reinforcing (Jacobi, 1964; Habenicht, 1984). That means, material without or with low tensile strength is supplemented by an element which can take up tensile forces and give the structure certain ductility. The influence of bolt inclination on the opening stability was examined by model experiments (Ham & Tsur-Lavie, 1970; Dunham, 1976;

[1] Dept. of Min. Geomech. & Geotech., Univ. of Min. & Metall., Al. Mickiewicza 30, 30-059 Kraków, POLAND

Raju & Ghose, 1982), field observations (Peng & Tang, 1984; Gale & Blackwood, 1987) and numerical experiments (Spang & Egger, 1990). In order to investigate the advantages and disadvantages of classic and fan shaped patterns several numerical calculations were carried out.

NUMERICAL CALCULATIONS

Numerical modelling was realised utilising the explicit finite difference programme FLAC v.3.4 (Itasca, 1998). The cable element formulation in FLAC considers more than just the local effect of reinforcement, its effect in resisting formulation is accounted for along its entire length. The input rock bolt properties in FLAC are bolt length, Young modulus, area, tensile yield-force limit, shear stiffness of the grout and cohesive strength of the grout. The spacing of cables perpendicular to the modelled cross-section was assumed to be 1.0 m. Both patterns of bolting were modelled as the roof reinforcement for the rectangular opening (6m x 3m) localised in stratified rock mass (fig.2).



The first task to solve was to find the optimal fan-shaped bolting pattern. Estimating the bolt's spacing resulting from the distribution of shear forces is quite easy. However, finding the optimal bolt's inclination may be very difficult. The optimum inclination is the one that gives maximum axial force in the bolt. The distribution of maximum principal stress trajectories may be obtained approximately only for the classical mechanical cases. That is why 35 numerical models were calculated to find the optimal inclination for the roof bolts. Finally, the estimated inclinations for the roof bolts (fig.1) were as follows: bolt #1 - 50^o, bolt #2 - 55^o, bolt #3 - 70^o. These calculations were performed assuming an homogeneous, isotropic and continuous rock mass. Of course, the optimal inclinations are the function of mechanical properties of the strata and may vary depending on rock mass geology.

The next task was to investigate the interaction of bolts with the laminar rock mass. Three different constitutive models provided in FLAC were adopted for modelling purposes: elastic model, plastic Mohr-Coulomb model and ubiquitous-joint model. Finally, after preliminary calculations the ubiquitous joint model was chosen for further examination. This model accounts for the presence of an orientation of the weakness in a Mohr-Coulomb model.

The yield may occur in either the solid or along the weak plane, or both, depending on the stress state, the orientation of the weak plane, and the material properties of the solid and weak plane. This model also provides the full information of the mode of failure. The rock mass geology and model geometry is presented in fig.2. The input mechanical properties of the materials and rock description are given in table 1.

Twenty-one numerical models were considered. Each model was calculated for the classic pattern and for the fan-shaped pattern. Material in the vicinity of an opening was modelled by a 0.1 m by 0.1 m grid size. All modelled cables were 2.5 m long. For each model stratum 1 and stratum 5 were assumed to be a siltstone. Four types of rock - coal, shale, siltstone and sandstone – were swapped among the strata 2-4 (see table 2).

Some models show significant differences between two bolting patterns considered. The axial force in cable element is almost always higher for the inclined bolts than for the bolts perpendicular to lamination. The classic pattern of bolting gives always slightly lower values of roof deflection (from 1.8 % to 5.7 %) than fan shaped one. The differences in the wall horizontal displacement are much smaller (0 % to 0.25 %), in some cases however classic pattern gives smaller wall displacement and in some cases the fan one. For some models (6, 8, 17, 18, 19) the classic pattern of bolting gives slightly lower values of floor vertical displacement (from 0.24 % to 2 %) than fan shaped one. But fan shaped pattern often (models: 1, 2, 4, 9, 10, 11, 12, 15, 20, 21) gives lower values of floor vertical displacement (from 0.05 % to 2%). Generally, the differences in the horizontal wall displacement and floor horizontal displacement are negligible. The one clear advantage of the classic pattern of bolting is that it always gives smaller roof deflections.

Table 1. Input material mechanical properties and rock description

Property	Rock strata (symbol)				Rock bolts
	siltstone (**sl**)	coal (**c**)	shale (**sh**)	sandstone (**sd**)	
elastic shear modulus, MPa	6000	1400	2000	10000	-
elastic bulk modulus, MPa	10000	2333.3	3333.33	16666.67	-
cohesion, MPa	3	2	1	5	-
internal angle of friction , deg	30	28	26	40	-
joint angle, deg	0	0	0	0	-
joint cohesion, MPa	1.5	1	0.75	2	-
joint friction angle, deg	26	20	15	30	-
joint tension limit, MPa	1	0.75	0.5	2	-
tension limit, MPa	2	1.5	0.75	3.5	-
Young's modulus, MPa	-	-	-	-	200000
grout shear stiffness, MPa	-	-	-	-	34400
cohesive strength of grout, MPa	-	-	-	-	0.8792
cable ultimate tensile capacity, MN	-	-	-	-	0.25
cross-sectional area of the cable, m^2	-	-	-	-	2.455e-4

Table 2. The model geology and calculation results

Numerical model	Strata sequence			Calculation results		
	2 (roof)	3 (wall)	4 (floor)	Advantage "fan"	Advantage "classic"	Balance "fan" & "classic"
1	**sl**	**sl**	**sl**	++		
2	**sl**	**c**	**sl**	++		
3	**sh**	**c**	**sl**			+
4	**c**	**c**	**sl**	++		
5	**sd**	**c**	**sl**			+
6	**sd**	**sl**	**sl**		++	
7	**sl**	**c**	**sh**			+
8	**sh**	**c**	**sh**		+	
9	**sd**	**c**	**sh**	+		
10	**sh**	**c**	**c**			+
11	**sd**	**c**	**c**		++	
12	**sh**	**c**	**sd**	+		
13	**sl**	**c**	**sd**			+
14	**sh**	**c**	**sd**			+
15	**c**	**c**	**sd**	+		
16	**sd**	**c**	**sd**			+
17	**c**	**c**	**sh**	+		
18	**c**	**c**	**c**		+	
19	**sd**	**sl**	**sh**	+		
20	**sh**	**sl**	**sh**			+
21	**sd**	**sh**	**sd**		+	

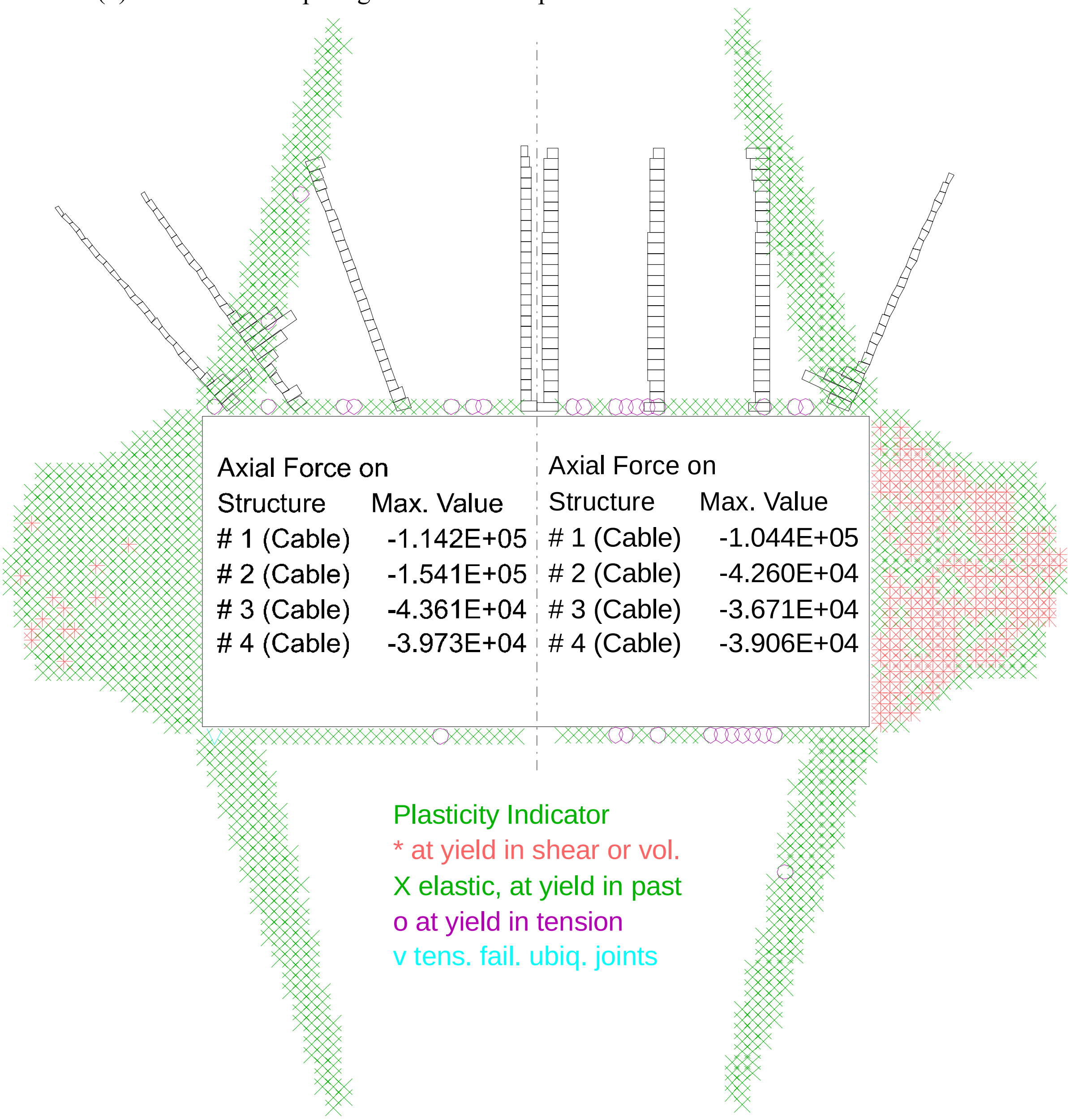
"+' advantage or balance
"++' considerable advantage

The increased roof deflections for the fan pattern may be explained by the action of the bolts. These bolts concentrate considerably more tensile stresses than for classic pattern. This results in higher axial forces in the bolts but for some cases it also generates different types of plasticity zones.

For some models, taking plasticity of strata under consideration, results in different types and ranges of plasticity indicators in the vicinity of the opening.

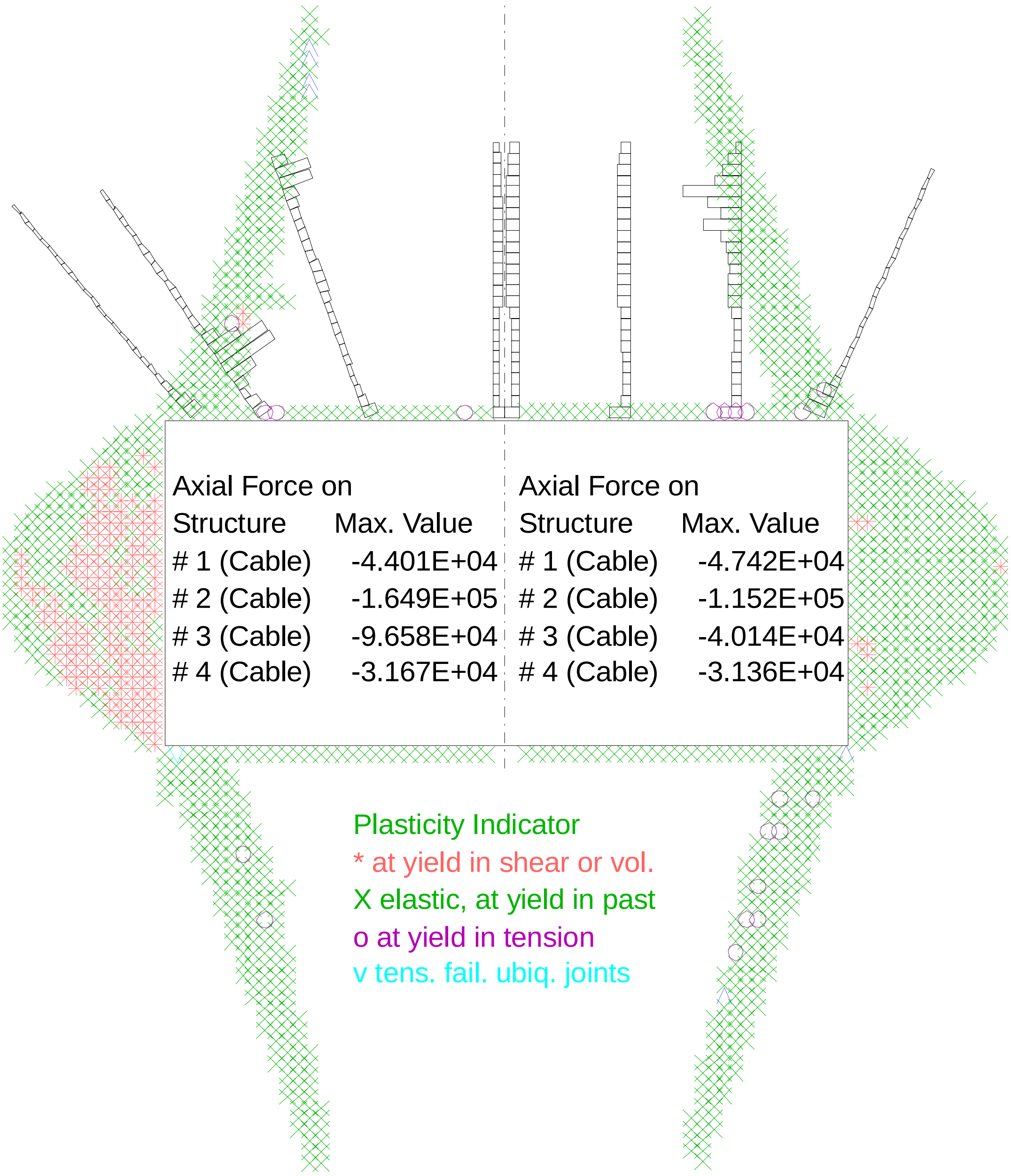
The summary of calculation's results is shown in table 2. For some models, the advantage of fan pattern over the classic one is very clear. Let us for instance consider the model 2. Distribution of plasticity indicators for model 2 is shown in fig.3. The shear failure zone in the wall is considerably limited for the fan pattern - shear failure occurs only in a few (14) elements. Comparing it with the classic pattern we have shear failure in 225 elements. The shear failure zone range reaches 1.8 m for the classic pattern. The application of fan pattern also significantly reduces tension failure in the floor and slightly reduces tension failure in the roof. The axial forces for all bolts in fan pattern are higher than for the classic one.

On the other hand, let us consider the distribution of plasticity indicators for model 6 (fig.4). The shear failure zone in the wall is considerably limited for the classic pattern - shear failure occurs only in a few (7) elements. Comparing it with the fan pattern we have shear failure in 154 elements. The



shear failure zone range reaches 1.4 m for the fan pattern. The axial forces for all bolts in fan pattern (except bolt 1) are higher than for the classic one.

Figures 3 and 4 present the most representative examples of the advantages of both considered patterns. It is very difficult to formulate the general recommendations for applications of different bolting patterns. For example, if we only take the 'considerable advantage' (++) under consideration, then for the stronger roof layer (sandstone) classic pattern should be applied. Similarly, for the weaker roof layer (shale) fan pattern should be used. These statements agree considerably with the results for models 1, 2, 4, 6 and 11. But the distribution of plasticity indicators for model 9 shows that fan pattern should be applied in spite of the presence of sandstone in the roof. This leads to the conclusion that interaction of bolts with the rock mass does not only depend on the mechanical properties of roof layer. The geology and the mechanical properties of the wall and floor should also be taken under consideration.



CONCLUSIONS

This paper examines the influence of roof bolts location on its interaction with rock mass in the vicinity of an opening. All the calculations described above may only be considered as qualitative. However, it can be stated that for some types of laminar rock mass, fan-shaped roof bolting may be favourable (unless the yield force limit in the bolt is not exceeded). For other types classic way of roof bolting is preferred. Usually fan-shaped roof bolting results in higher axial forces in cable elements.

Detailed consideration of all calculated numerical models leads to the conclusion that interaction of bolts with the rock mass does not only depend on the mechanical properties of roof layer. We have to take under consideration mechanical properties and geology of all strata in the vicinity of an opening. After constructing the numerical model we should check if the fan shaped pattern is favourable for the given conditions, for example, for the bolts inclinations presented in this paper. If not, then we use classic pattern of bolting. If fan shaped pattern gives favourable distribution of plasticity indicators then we should try to find the optimal (i.e. giving maximum axial force in the bolts) bolts inclination.

FLAC seems to be a powerful numerical tool to analyse the mechanical interaction of rock bolts with the rock mass around the opening. Application of that numerical code might be very useful for selecting the proper bolting pattern.

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REFERENCES

Cała M. 1997. The influence of rock mass geology on rockbolting design. Ph.D. Thesis. University of Mining & Metallurgy. Kraków. 152 pp. (in polish).

Dunham R.K. 1976. Model Studies of Resin-Anchored Bolting Reinforcement. *Colliery Guardian*. Nov. pp.592-603.

Gale W.J., Blackwood. R.L. 1987. Stress Distributions and Rock Failure Around Coal Mine Roadways. *Int. J. Rock. Mech. Min. Sci. & Geomech. Abstr.* Vol.24, No. 3, pp.165-173.

Gałczyński S. 1973. Static calculations of roof bolts. *Archives of Mining Sciences*. Vol. 18, No. 1, pp. 27-45. (in polish)

Habenicht H. 1984. An anchoring effects - Our present knowledge and its shortcomings. *Proc. of Int. Symposium on Rock Bolting* (edited by O. Stephansson). A.A. Balkema. Brookfield. pp.257-268.

Ham van F., Tsur-Lavie Y. 1970. Reinforcement Effect and Action of Perpendicular and Inclined Roofbolts in Layered Rock Mass. *Proc. of 2nd Congress of ISRM*. Vol.2. pp.457-467.

Itasca Consulting Group Inc. 1998. Fast Lagrangian Analysis of Continua v. 3.4. Users Manual. Minneapolis.

Jacobi O. 1964. The Origin of Roof Falls in Starting Faces with the Caving System. *Int. J. Rock. Mech. Min. Sci. & Geomech. Abstr.* Vol.1, pp.313-318.

Jeffrey R.G., Daemen J.J.K. 1984. Analysis of rockbolt reinforcement of layered rock using beam equations. *Proc. of Int. Symposium on Rock Bolting* (edited by O. Stephansson). A.A. Balkema. Brookfield. pp.173-185.

Peng S.S., Tang D.H.Y. 1984. Roof bolting in underground mining: State of art review. *Int. Journ. Min. Eng*. No. 2 str.1-42.

Peng S.S. 1986. *Coal Mine Ground Control*. John Wiley & Sons. Second edition.

Raju N.M., Ghose A.K. 1982. Strata Reinforcement with Bolting and Wire-Rope Systems - A Comparative Study. *Int. J. Rock. Mech. Min. Sci. & Geomech. Abstr.* Vol.19, pp.103-106.

Snyder V.W. 1984. Analysis of beam building using fully grouted roof bolt. *Proc. of the Int. Symposium on Rock Bolting* (edited by O. Stephansson). A.A.Balkema. Brookfield. pp.187-194.

Spang K., Egger P. 1990. Action of Fully-Grouted Bolts in Jointed Rock and Factors of Influence. *Rock Mechanics and Rock Engineering*. No 23. pp.201-209.

Stimpson B. 1984. The influence of rock bolt location on the reinforcement of horisontally bedded roofs by full column grouted bolts. *Proc. of Int. Symposium on Rock Bolting* (edited by O. Stephansson). A.A. Balkema. Brookfield. pp.195-204.