

TESTS OF PERSONAL CABLE LIFT WITH THE POSSIBILITY OF SOLUTION COMPARISON IN SIMULATION PROGRAMReceived: 2009-7-20
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The article describes the testing of personal cable lift „fall” before its first starting up. Technical tests are conducted by building societies normative with the participation of Technical inspection of SR where is important the nominal speed of cage. After this speed exceeding the other mechanisms are setting into operation, by the help of them the lift is off. Effects of these mechanisms are verified in agreement with valid standards and in the case of fulfillment of demands, the lift can be put into operation.

Key words: *test, velocity, safety*

INTRODUCTION

After lift mounting every manufacturer has to perform so called „primary“ safety test, test of accuracy and test of utility. Authorized person (for example Technical inspection, TÜV Slovakia et al.) performs, regulates and evaluates the test because the activity of the lift complex is conditional on strict safety regulation. Every safety device on the lift has to fulfil these criteria. The task of these devices is to limit and prevent to the next operation in case of state identification which is not in accord with some categorial specified safety parameters.

The article is centred on the safety gear action in test performance and the consequence of these facts is the generation of stress to the axis x,y in the guides. Calculated values and input parameters of the safety gears are the basis of dynamic calculation of the lift cage free fall in suitable simulation program. The test of safety gear was realized by procedure which results from valid standard STN EN 81-1+AC part 1: Electric lifts and Regulation of government 571/2001 Collection of laws, as amended by Regulation of government 327/2003 Collection of laws.

DESCRIPTION OF TEST COMPONENTS

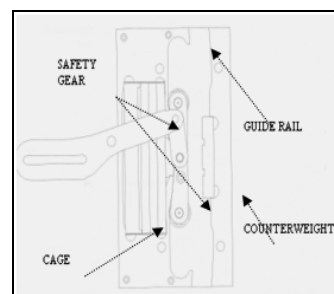
The test of safety gear efficiency and their impingement on guides was realized at the personal freight traction lift of type marking ONTV 2000. The lift was

made and delivered by firm LIFTEX, Ltd. Košice to the company VSH, Inc. Turňa nad Bodvou. There is a basic characteristics of the lift in the Table 1.

Table 1. **Basic technical data of the lift**

Loading capacity	2000 kg
Travel	33,4 m
Rated speed	0,63 m/s
Number of stations/platforms	6/6
Drive	electric traction
Feed array	3/PE AC 400/230V 50Hz, TN-S
Control	button

The producer in lift supply used self locking safety gear as a element of protective device against the excessive speed of the lift cage above and deorsum. The Fig. 1,2,3 illustrate behaviour of jaw safety gears which clasp guides in the moment of nominal speed excess.

Figure 1. **Rest position**

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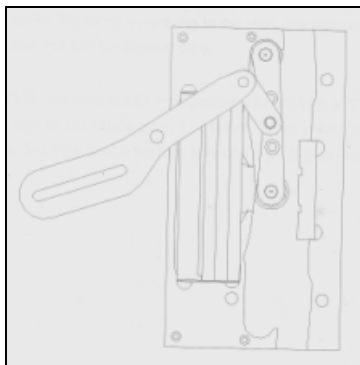


Figure 2. Downwards engagement

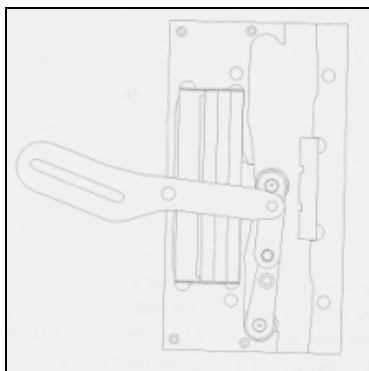


Figure 3. Upwards engagement

Used safety gear was made by external firm and delivered on the basis of requirements of lift manufacturer which are listed in the certificate of safety gears and they are:

1. admissible load deorsum/above: 4023 kg (max), 881 kg (min)
2. admissible brake force: 28659 N (max), 6629 N (min)
3. maximum rated speed: 2,0 m/s (cage), 2,0 m/s (counterweight)
4. maximum access speed of speed limiter : 2,5 m/s (cage), 2,5 m/s (counterweight)
5. thickness/width of guide: 16 mm/42 mm
6. minimal parachute: 25 mm

INPUT PARAMETERS FOR GUIDE STRESS CALCULATION

The action of instantaneous safety gear generates force stress to the axis x and y by guiding jaws in the site of grip and this stress can not exceed the limit of admissible stress normative STN EN 81-1+AC (Fig. 4).

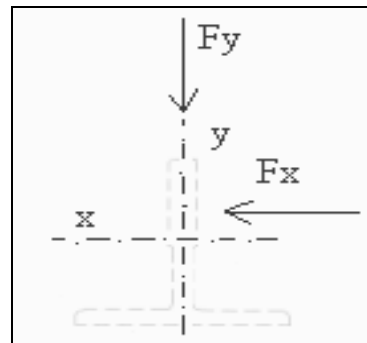


Figure 4. Axis of guide

For this calculation we need following data (Tab. 2):

Table 2. Input parameters

Parameter	Designation	Value
Number of guides	n	2
Weight of empty cage	K	1800 kg
Load capacity	Q	2000 kg
Weight of empty cage and parts of lift flex	P	1870 kg
Vertical distance of the centres of guide jaws	h	3130 mm
Distance of the centre of gravity of rated capacity from vehicle	x_q y_q	325 mm 200 mm
Distance of centre of gravity of cage weight from guide	x_p y_p	50 mm 30 mm
Impuplse coefficient in the action of insantaneous safety gear	k₁	2
External yarding distance between consoles and guides	l	2000 mm
Buckling coefficient	ω	1,52
Modulus of section – moment of resistance	W_x W_y	30,4.10 ³ mm ³ 23,4.10 ³ mm ³
Cross-section area of guide	A	2264 mm ²
Minimal radius of gyration	i_y	25,6 mm
Thickness of clutch between flange and head of guide	c	10 mm
Admissible stress in the action of safety gears normative STN EN 81-1+AC cl. 10.1.2	σ	205 Mpa

STATIC CALCULATION OF GUIDE BY OPERATION OF INSTANTANEOUS SAFETY GEAR

At first it is calculated the forces from guide flex in various cases of loading (F_x , F_y), moment of flexion (M_x , M_y), buckling force which is causing by cage (F_k) and slenderness ration (λ).

Bend stress to the axis x of the guide

$$F_y = \frac{k_1 \cdot g_n \cdot (Q \cdot y_q + P \cdot y_p)}{\frac{n}{2} \cdot h} \quad (1)$$

$$F_y = \frac{2,9,81 \cdot (2000 \cdot 200 + 1870 \cdot 30)}{\frac{2}{2} \cdot 3130} N = 2859 N$$

$$M_x = \frac{3 \cdot F_y \cdot l}{16} \quad (2)$$

$$M_x = \frac{3 \cdot 2859 \cdot 2000}{16} Nmm = 1072126 Nmm$$

$$\sigma_x = \frac{M_x}{W_x} = \frac{1072126}{30,4 \cdot 10^3} MPa = 35 MPa \quad (3)$$

Bend stress to the axis y of the guide

$$F_x = \frac{k_1 \cdot g_n \cdot (Q \cdot x_q + P \cdot x_p)}{n \cdot h} \quad (4)$$

$$F_x = \frac{2,9,81 \cdot (2000 \cdot 325 + 1870 \cdot 50)}{2 \cdot 3130} N = 2330 N$$

$$M_y = \frac{3 \cdot F_x \cdot l}{16} \quad (5)$$

$$M_y = \frac{3 \cdot 2330 \cdot 2000}{16} Nmm = 873850 Nmm$$

$$\sigma_y = \frac{M_y}{W_y} = \frac{873850}{23,4 \cdot 10^3} MPa = 37 MPa \quad (6)$$

Buckling effort

$$F_k = \frac{k_1 \cdot g_n \cdot (P + Q)}{2} \quad (7)$$

$$F_k = \frac{2,9,81 \cdot (1870 + 2000)}{2} N = 37965 N$$

$$\lambda = \frac{l}{i_y} = \frac{2000}{25,6} = 78 \rightarrow \omega = 1,52 \quad (8)$$

$$\sigma_k = \frac{(F_k + k_3 \cdot M) \cdot \omega}{A} \quad (9)$$

$$\sigma_k = \frac{37965 \cdot 1,75}{2264} MPa = 29 MPa$$

Combined bend stress and buckling effort

$$\sigma_c = \sigma_k + 0,9 \cdot (\sigma_x + \sigma_y) \quad (10)$$

$$\sigma_c = 29 MPa + 0,9 \cdot (35 + 37) MPa = 94 MPa$$

Bend stress of guide flange

$$\sigma_F = \frac{1,85 \cdot F_x}{c^2} \quad (11)$$

$$\sigma_F = \frac{1,85 \cdot 2330}{10^2} MPa = 43 MPa$$

It did not ponder over stress M from auxiliary devices by calculation of buckling effort. The value of buckling coefficient $\omega=1,75$ has been set by manufacturer and it is superior to value after calculation of slenderness ratio.

There is a comparison of calculated values of guide stress to values which rule the standart STN EN 81-1+AC in the table 3. The comparison of the results determines if the assembled safety gears fulfil the conditions of the standard on the part of safety of lift operation.

Table 3. Comparison of the results

Viewed part of the lift	Mode of stress	Comparison to technical request of the standard	Request are executed	
			yes	no
Test of the instantaneous safety gears	σ_x	$35 MPa \leq 205 MPa$	X	
	σ_y	$37 MPa \leq 205 MPa$	X	
	σ_k	$29 MPa \leq 205 MPa$	X	
	σ_c	$94 MPa \leq 205 MPa$	X	
	σ_f	$43 MPa \leq 205 MPa$	X	

CONCLUSION

The test of safety gears was realized by driving of centric led and suspended cage deorsum with uniformly distributed loading along, in running of lift machine up to impact of safety gear and stopping (stoppage) of cage on the guide inder the proviso that:

⇒ The cage had to lead in rated load and it had to move deorsum with rated speed.

Braking distance of the lift cage is negligible by using of these safety gears. Sliding safety gear is more suitable type of safety gear for simulation model creation, thereby the stopping of cage on the guides does not cause by feeling of „tearing“ but „sliding“ and it has an impact on passengers security, too.

In this case the cage has to be loaded by 125% rated load and it has to move by rated speed or by lower speed. We are able to determine total fall, braking distance on the guides and slipping line of the rope on the speed limiter from the results of measuring.

Simulation of running safety gears action to the cage guide by free fall and comparison of static calculation to dynamic calculation are the subjects of the next solution of the grant project.

Acknowledgement:

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RECOLTIVATION AND SUSTAINABLE DEVELOPMENT OF COAL MINING IN KOLUBARA BASIN

by

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Coal plays a fundamental role in global development, but the coal mining industry exerts impact on the environment, society, and economy. Kolubara Coal Company produces about 30 million tonnes of coal, and digs about 70 million m³ of overburden per year. The main result of surface coal is certainly taking agricultural land, so that surface mines, which affect large areas in Kolubara, about 100 hectares a year, causing a number of problems related to the recultivation of degraded area after coal extraction.

The lignite extraction through the method of opencast mining in Kolubara is about 60 years old. The previous exploitation usage is characterised by the fact that the disposal of overburden is made non-selectively, whereas the top soil layer is not being preserved. The recultivation is carried out in parallel with overburden excavation. It is necessary to preserve the fertile soil layer through selective excavation in order to bring the soil back to its previous purpose – agricultural production.

The objective of this paper is mainly to point out the need for the further expansion of the utilisation of fossil fuels, which in turn reduces the emission of CO₂, and thus reduces or prevents global climate changes on Earth. In addition to that, bringing back deteriorated terrains to their previous purpose – agricultural production, or the afforestation – contributes to the maintenance of ecological balance in nature, which then makes coal mining sustainable.

Key words: *mining, recultivation, sustainable development, economic development, environment, social responsibility*

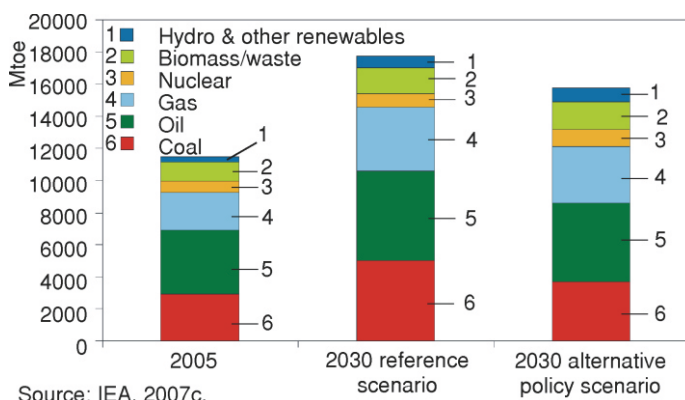
Introduction

A widely accepted definition of sustainable development is development that meets the needs of the present generation without undermining the capacity to meet future generations' needs. Sustainable development is a synthesis of three fields of our activity: economic development, environment protection, and social responsibility.

The open-pit mining of lignite is distinctive through the fact that it requires large terrain surfaces. Lignite is a type of coal which is relatively poor in quality and therefore mostly

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used for the production of electrical energy in thermal power plants. In order to make this process cost-efficient, it is necessary to achieve a high coal production rate. On the other hand, a high production of electricity and thereby of coal is subject to the energy demands of modern society.



Source: IEA, 2007c.

Figure 1. Energy demand changes according to two scenarios for 2030 (color image see on our web site)

2005 to 34.1 GtCO₂ in 2015 and 41.9 GtCO₂ in 2030. In the WEO 2007 alternative policy scenario, emissions rise to 31.9 GtCO₂ in 2015 and 33.9 GtCO₂ in 2030. In the IEO 2007 forecast, CO₂ emissions in the reference case increase from 26.9 GtCO₂ in 2004 to 33.9 GtCO₂ in 2015 and 42.9 GtCO₂ in 2030 [1].

Table 1. Quantity of air pollutants (CO₂, SO₂, and NO_x) emitted into the atmosphere in Serbia

CO ₂ [kT per year]	SO ₂ [kT per year]	NO _x [kT per year]
33501	449.33	59.03

According the research in Serbia at the national level, the quantity of air pollutants (CO₂, SO₂, and NO_x) emitted into the atmosphere in Serbia is presented in tab. 1 [2].

For a country (either developed or developing) to understand the role of energy use at the national level, it is necessary to understand the relationship of energy use to economic activity and social well-being,

and the relationship between energy and GDP indicates the economic development of a country. Industrial production in modern societies is kept in pace by socio-economic growth [3].

Depending on energy resources available, any country may choose the method of its utilisation. The Republic of Serbia has several coal basins, with three of them being dominant: the Kosovo, Kolubara, and Kostolac coal basins. According the Strategy of Development of Energy System in the Republic Serbia up to 2015, and according the literature, the greatest geological energy resource in Serbia is coal (about 80%), particularly low rank lignite (about 65%) [4]. Lignite is the largest natural energy source in Serbia. The share of coal is about 88% in total, and possible energy production using the remaining reserves available (small rivers, small coal mines, and oil shale), can be about 10% most [5, 6].

According to the IEA World Energy Outlook 2007 (WEO 2007) reference scenario, "global primary energy demand is projected to increase by 55.1% between 2005 and 2030, to a total of 17.721 million tones of oil equivalent (Mtoe)". Figure 1 represents energy demand changes according to two scenarios for 2030. All of the energy growth forecasts have major CO₂ emission consequences. The WEO 2007 reference scenario sees CO₂ emissions increase from 26.6 gigatonnes CO₂ (GtCO₂) in

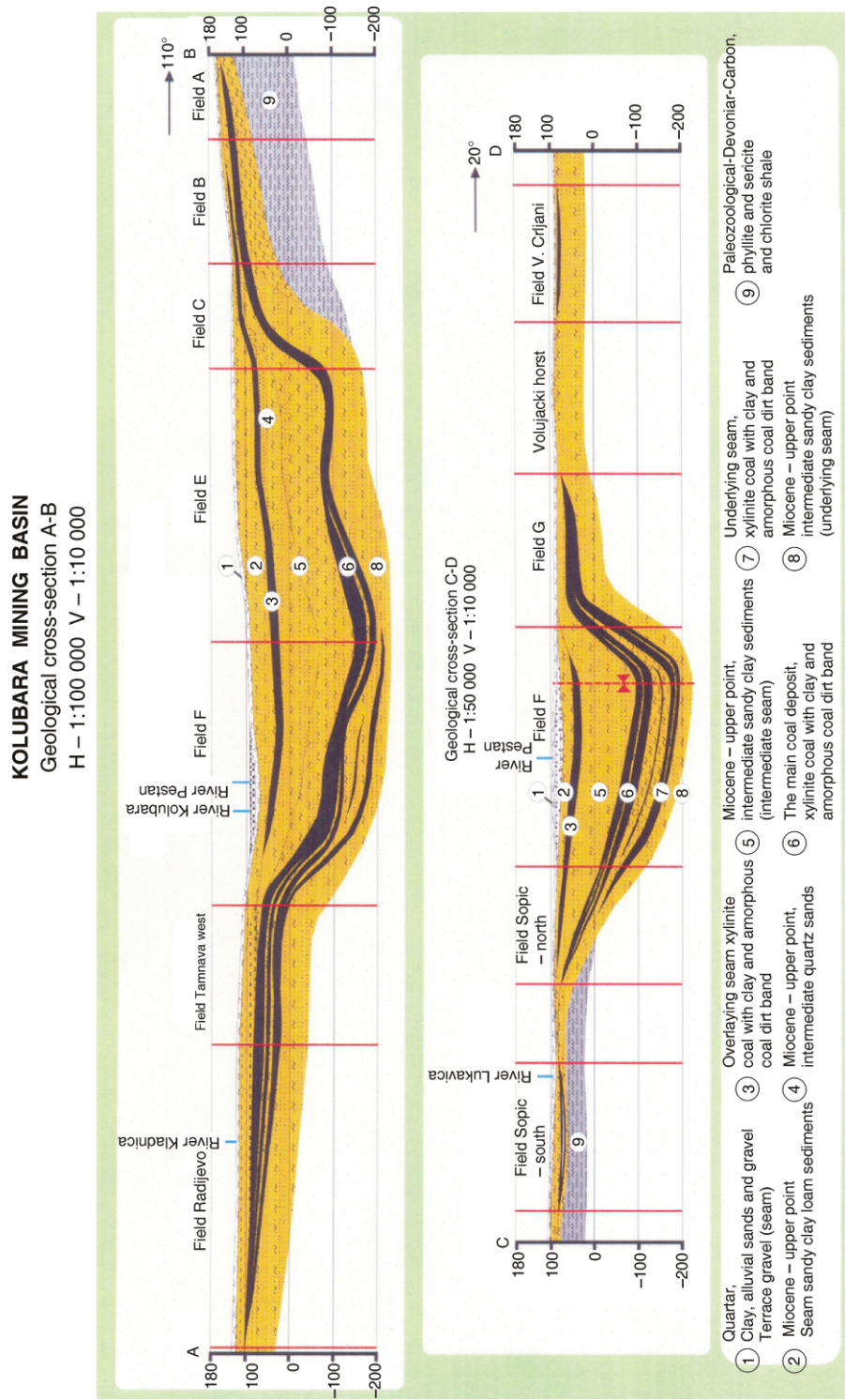


Figure 2. Typical geological profiles throughout the Kolubara coal basin (Source Kolubara coal basin)

Material and methods

Method of lignite extraction

The coal from Kolubara basin is lignite of relatively low quality, *i. e.* of low carbonisation degree, and therefore it is largely used for combustion in thermal power plants and for the generation of electricity. The Kolubara coal was formed some 10 million years ago in shallow waters of the Panonian sea. The coal was formed in the time when the climate in this area was a warm, subtropical one. Figure 2 shows typical geological profiles of the Kolubara coal basin.

The lignite extraction through the method of open-cast mining in Kolubara is about 60 years old. It is a period when there were major changes in operating conditions. The equipment, laws, regulations, even the approach to open-pit mining has changed in compliance with international trends. The Kolubara coal basin is situated 50 km in the south-east of Belgrade, and occupies a territory of approximately 600 km². The coal production is being carried out in four

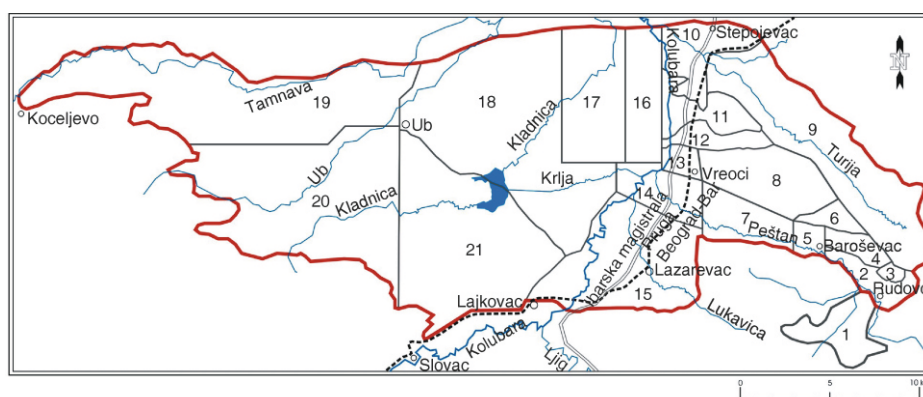


Figure 3. Kolubara basin divided into mining fields

1 – field Kruševica, 2 – field Rudovci, 3 – field A, 4 – field B, 5 – field C, 6 – field Baroševac, 7 – field E, 8 – field D, 9 – field Turija, 10 – field Stepojevac, 11 – field Veliki Crljeni, 12 – field Volujak-Vreoci, 13 – field G, 14 – field F, 15 – Šopić-Lazarevac, 16 – field Tamnava-east, 17 – field Tamnava-west, 18 – field Radljevo, 19 field – Trlić, 20 – field Zvizdar, 21 – field Ruklade

Table 2. Coal and overburden production in Kolubara in 2008

Open pit	Realised overburden production [m ³]	Realised coal production [t]
Field B	2,981,897	1,091,320
Field D	39,590,875	14,069,026
Tamnava – eastern field	7,998,299	5,016,965
Veliki Crljeni	1,923,670	–
Tamnava – western field	24,672,871	10,361,665
Total	77,167,612	30,538,976

open-pits: fields C and D, Tamnava eastern field and Tamnava western field [7]. Figure 3 shows the mining fields of Kolubara coal basin.

An average annual production amounts to approximately 30 million tonnes of coal and about 70 million m³ of overburden. Table 2 shows the coal and overburden production in Kolubara

in 2008. The coal and overburden are mainly excavated by bucket wheel excavators and transported by conveyor belts.

Figure 4 shows overburden and coal benches in the open-pit mine Kolubara.

The process of coal excavation consists of several cycles: the cycle of excavation, disposal, and recultivation. The mining works begin after the expropriation. First, the preparation of the terrain envisaged for mining is conducted. The preparation of the terrain necessitates the demolition of constructions, felling of trees, relocation of watercourses, roads, *etc.* Then the overburden is excavated, transported and dumped using the mining machinery. Today, bucket wheel excavators, conveyor belts and stackers are mainly used. When the coal seam appears, such a seam is excavated and transported to the crushing plant.

Based on the process of coal excavation, explained up to this point, and its relation to the recultivation, there are few important characteristics that stand out:

- notwithstanding the occupancy of large areas and the change in the purpose of the land, large parts are still brought back to the previous state; it virtually means that they are temporarily occupied by mining activities, in a period of some ten years, and that they can be reused as before following this period,
- a part of the area occupied by the exploitation cannot be brought back to the state prior to the beginning of the exploitation,
- area occupied by the external dump, although it is generally (as a rule) higher than the terrain before mining activities, is still brought back to the state so that it can be reused, and
- at the end of mining activities, the mine becomes the owner of large areas of agricultural land and forests; according to the law, the owner of an agricultural land and forest is obliged to work the soil and control forest husbandry.

Figure 5 represents the paths of landscape development following a disturbance [8].

In practice, there is a number of ways to resolve this issue. There are many possibilities for, and many examples of an efficient utilisation reclaimed areas of lignite mines in the world [9-13].



Figure 4. Overburden and coal benches in the open-pit mine Kolubara

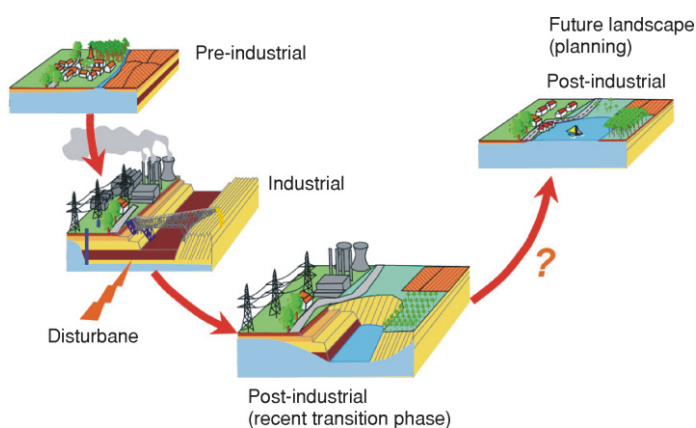


Figure 5. Landscape development following a disturbance (Source Huttli, R. F.)

Method of recultivation of Kolubara open pit mine

Recultivation is a process whereby a part of a dump is brought back to the state of land similar to the one before the excavation. In this way, the negative impact of the excavation of overburden and coal is lessened. The recultivation process is a legal obligation, which is to be implemented according to a recultivation project. The recultivation project is a mandatory, integral part of a mining project. There is a need for a national system of quality control inspection for land recultivation and reclamation sites, and provision for training in the special problems of managing reclaimed lands [14]. It consists of two parts: technical recultivation and biological recultivation and reclamation.

Technical recultivation is a procedure of levelling and preparation of a dump area for the biological recultivation. The dump, especially its vertical part, is highly rough and it is necessary to put it into such a state which enables biological recultivation. Criteria for the creation of a dump are that it is stable, technically, and economically justified, and that it is not ideally flat. Before the biological recultivation begins, the quality of land is to be investigated, in two directions. Primarily, it has to be determined whether the soil contains an inadmissible concentration of harmful, toxic matters such as heavy metals. Then the soil quality is determined, in terms of the contents of humus matters, minerals, and acidity, in order to define corrective measures. If the soil contains heavy metals, their concentration and mobility have to be identified. Then we should determine if and which type of agricultural products may be cultivated, or the type of forestation that would be needed [15].

All these factors, area topography and its quality define the recultivation type. Flat parts are used for the agricultural reclamation and production, while rough parts and slopes are afforested [16]. In addition to the dump area, there is also a depression that remains after mining activities, which is naturally being filled with water. It results from the fact that the excavated coal is carried away and only the overburden is brought back to the working cavity, so there is a deficit of material. As a result of the processes of mining and recultivation, *i. e.* the land and watercourse restructuring, we obtain three units. The first unit is an external dump, which is restored by agricultural species at its flat parts of slopes while the rough parts are reclaimed by for-

Table 3. Overview of the existing condition of soil in reclaimed areas

Field	Expropriated area [ha]	Dump [ha]		Reclaimed [ha]			
		Internal	External	Forests	Agricultural land	Orchards	Seed-plots
Field D	2.754	1.231	723	509	235	16	12
Field B	885	–	–	301	6	–	–
Tamnava-eastern field	2.219	825	378	60	23	–	4
Tamnava-western field	618	192	–	–	–	–	–
Total	6.476	2.248	1.101	870	264	16	16

est seedlings. The second and largest part is the area of an internal dump, which is also reclaimed, depending on the type of the terrain and the composition of the soil. The third part is a lake, or a number of them, that could be also arranged to serve as tourist facilities, which is a common practice in some countries, or for other purposes [17, 18].

The recultivation is carried out in parallel with overburden excavation. Today we have about 1 100 ha of reclaimed land in Kolubara, about 870 ha of forest seedlings, generally situated in rough parts of a dump and about 260 ha of agricultural land. Table 3 shows the overview of the existing condition of the soil in reclaimed areas.

As we can see from given information, open-pit lignite extraction in Kolubara coal basin has minimised by approximately 6500 ha, the cultivable and arable land and wood area. In order to reduce negative environmental effects, it is necessary to recultivate, reclaim, and afforest or convert into cultivable agricultural land all of the 6500 ha, which are in the structure of the expropriated land in the Kolubara coal basin. Figure 6 shows reclaimed soil turned into an arable agricultural land and fig. 7 shows the afforested reclaimed soil in the open-pit mine Kolubara.



Figure 6. Reclaimed arable soil



Figure 7. Afforested reclaimed soil

Due to the coal extraction and ground dumping, a large number of lakes have been formed, by intersecting certain watercourses of rivers, and streams which even now fill the latter with water, and by accumulating water in certain depressions and mining shifts which were formed in ground dumps. During summertime, the accumulated water may be very successfully used for the irrigation of the crops that will be grown on the reclaimed surfaces. The seventeen



Figure 8. Reclaimed depression of the pit



Figure 9. Lake during the reclamation

lakes could be used, as well as for the irrigation, for fish and spawn breeding. Figure 8 shows one of the reclaimed depressions in the open-pit mine Kolubara and fig. 9 shows a lake in the process of reclamation.

Chemical analysis

Maximum allowable concentrations of hazardous and harmful substances in soil differ from country to country. Table 4 shows maximum allowable concentrations (MAC) of trace elements in agricultural soils, proposed or given in directives in various countries and in different years [19].

Table 4. Maximum allowable concentrations of trace elements in agricultural soils proposed or given in the directives in various countries, and different years [19]

Chemical element	Poland (1993)	UK (1987)	Germany (1992)	Euro comm. (1986)	USA (1993)
Cadmium (Cd)	1-3	3-15	1.5	1-3	20
Lead (Pb)	70-150	500-2000	100	50-300	150
Mercury (Hg)	5	—	1	1-1.5	8
Arsenic (As)	30	10	—	—	—
Chromium (Cr)	50-80	—	100	50-150	1500
Nickel (Ni)	30-75	20	50	30-75	210
Fluorine (F)	—	—	—	—	—
Copper (Cu)	30-70	50	60	50-140	750
Zinc (Zn)	100-300	130	200	150-300	1400
Boron (B)	—	—	—	—	—

In Serbia, maximum allowable quantities of hazardous and harmful substances in soil and water for irrigation and the methods for their examination (Official Gazette of the Republic of Serbia No. 23/94), which may damage or modify the production capacity (fertility) of an agricultural land and the quality of water for irrigation, are envisaged in the rules on maximum allowable concentrations of hazardous and harmful substances. Hazardous substances, in terms of the rules, are: cadmium, lead, mercury, arsenic, chromium, nickel, and fluor; while harmful substances are: copper, zinc, and boron. Table 5 shows maximum allowable concentrations of hazardous and harmful substances as prescribed in the Republic of Serbia [20].

In order to perceive the environmental aspect of the current state and further preservation of the soil in the area of the open-cast mine Kolubara, which is mainly agricultural, analyses of the overall contents of heavy metals in the soil have been made, in the mine itself and in its vicinity, which is the area of future mining operations. The collected data serves to formulate and further enforce certain regulatory and institutional procedures which contribute to the soil keeping its economical and social potential after the reclamation. Table 6 shows the analyses of the overall content of heavy metals.

Table 5. Maximum allowable concentrations of hazardous and harmful substances prescribed by the rules in the Republic of Serbia

Chemical element	Maximum level in soil [mg per kg soil]	Maximum level in water [mg per liter of water]
Cadmium (Cd)	3	0.01
Lead (Pb)	100	0.1
Mercury (Hg)	2	0.001
Arsenic (As)	25	0.05
Chromium (Cr)	100	0.5
Nickel (Ni)	50	0.1
Fluorine (F)	300	1.5
Copper (Cu)	100	0.1
Zinc (Zn)	300	1.0
Boron (B)	50	1.0

Table 6. Overall content of heavy metals in the soil.

Depth [cm]	Fe [%]	Mn [mgkg ⁻¹]	Cu [mgkg ⁻¹]	Zn [mgkg ⁻¹]	Co [mgkg ⁻¹]	Ni [mgkg ⁻¹]	Cr [mgkg ⁻¹]	Pb [mgkg ⁻¹]	Cd [mgkg ⁻¹]
Sample 1									
0-30	4.59	714	34.40	54.71	17.24	173.83	85.80	26.09	–
30-60	5.45	718	33.30	58.69	18.31	192.29	97.44	30.60	–
60-90	4.50	660	34.50	62.42	20.30	204.82	109.17	34.14	–
Sample 2									
0-30	4.46	650	29.55	50.02	17.29	159.44	83.32	30.60	–
30-60	4.34	661	27.00	46.60	17.03	155.03	89.43	27.89	–
Sample 3									
0-30	4.38	695	33.40	56.00	18.26	170.10	92.00	33.66	–
30-60	4.25	668	26.15	48.88	17.75	130.51	79.28	28.66	–
Sample 4									
0-30	3.70	658	29.10	50.73	17.32	161.12	88.54	24.82	–
30-60	4.17	689	29.90	53.07	18.72	169.15	95.99	28.70	–
Sample 5									
0-30	3.72	543	24.70	37.41	17.06	231.23	123.31	21.06	–
30-60	4.90	548	24.40	37.21	17.32	235.39	108.67	18.41	–

The analysis of the overall content of heavy metals indicates an increased content of some heavy metals (mainly nickel and chromium, shading values), of which the presence relates to the origin of these alluvial lands. Such analysis is the analysis of potential pollution agents, because their accumulation in herbal products may cause the removal of these products from the further utilisation. As such large concentrations of heavy metals appear mostly in deep seams, in the process of soil reclamation, the possible soil pollution caused by these metals has to be considered, as well as measures which could reduce their accessibility to the flora [21].

Social aspects of mining extraction and recultivation

Sustainable development is a synthesis of three fields of our activities: economic development, environmental protection, and social responsibility. The social responsibility of the company is defined as a balance of working and personal life of the employees, equal opportunities, diversity at the workplace (ethnic minorities, handicapped and older people), ensuring of retraining of the dismissed employees, *etc.* The European Commission defines corporate social responsibility (CSR) as a conception under which the company integrates the social and environmental points of view into its business and into communication with the interested parties [22].

In addition to the afore-mentioned, typical changes, and the condition of the environment, it would also be interesting to discuss the flow of other resources, *i. e.* of social changes accompanying the exploitation. At the beginning of its operation, a mine has a whole deposit (coal) and mining machinery available to it. There is not enough skilled staff, considering that the population in the vicinity is agricultural, and there is no developed industry supporting said mining activities.

During mining operations, excavations lead to the decrease in coal reserves and to the increase in the number of skilled workers. The occupied area, and therefore the reclaimed area, are enlarged. It leads to the increase in the number of inhabitants in the vicinity, due to the increase in monetary flow and the demand for experts. The starting point is typically the acceptance of sustainable developmental principles at board-room level as corporate goals, and then informing the workforce, investors, and others of that commitment. Relevant employees need to be engaged as a first step in the practical application of sustainable development principles, followed by the gradual extension of training in sustainable methods of working to the workforce as a whole [23]. Mining companies were among the first to introduce the practice, now common, of building and maintaining schools, clinics, and sports facilities for their employees. It is not uncommon for them to be made available to other people living in the vicinity of the company location [24, 25].

At the end of the coal exploitation, there is no coal; however, there are large agricultural and forest areas. Both the structure and the number of inhabitants are suitable for industry, not agriculture or forestry. There are also machines with repair shops and plants, which formerly served as a support to the coal production. However, they cannot be used for land farming; the same is the case with the existing population structure. Big social problems then arise. A whole functional environment which has been developing for many years is no longer functional because mineral resources are not renewable, but rather limited by time and space.

The whole environment turns into an environment with new characteristics and non-functional social content. At that, it has to comply with the sustainable development. The solution for this problem may go into two directions. One being that during the enlargement of agricultural and forest areas after the recultivation process, it is necessary to adapt the compa-

nies which had been specialised for the production of mining equipment and to turn them into profitable ones. In addition to that, factories and repair shops, unless market oriented, should be turned into rentable factories of related products.

Results and discussion

All of the issues in connection to the relationship between an open-pit mine and the environment are defined by relations arising from the soil pollution. The technological process of lignite exploitation causes, to a certain extent, the change, *i. e.* deterioration, of the original morphological and pedological structure of the terrain and soil, and the release of harmful substances – mineral dust into the air, in a certain concentration. The main impact is related to the deterioration of the upper seam structure during mining operations. The above negative impact may occur as a result of the excavation of the upper seam and its inadequate disposal, and of mixing the upper seam with the lower one, as well as other barren materials. The impact of lignite exploitation also represents a potential contamination of the upper seam due to the precipitation of dust from the air. In addition to the afore-mentioned impacts, it is necessary to emphasise the disappearance of the arable upper seam as a result of the building-up in infrastructure facilities (roads, railroad tracks, water-ways, industrial areas, *etc.*) and of the change in the purpose of the soil in the vicinity of the mine.

In any case, open-cast coal mining leads to the disturbance of geological layers where different sedimentary products are being mixed, which means that a completely new, anthropogenic land, *i. e.* substratum, is created, without any resemblance to the original land, which is now called a deposol. The previous exploitation usage is characterised by the fact that the disposal of overburden is made non-selectively, whereas the top soil layer is not being preserved, which can later cause a number of complex problems in making the overburden suitable for herbal production, and in bringing the land back to its previous state.

Visual pollution as a criterion of the relationship between a mine and its environment implies that the characteristics of the landscapes' appearance are a qualitative factor which occurs as an element of degradation of the existing and established relations. In order to switch from a descriptive impact assessment in this domain to quantitative methods, which include a complex valorisation of the area, it is necessary to perform a series of specific analytical procedures during which high-technology graphic and visual pieces of information are needed. The impact of open-cast lignite exploitation on modifications of landscape characteristics, in terms of morphological modifications of the terrain, indicates the creation of large-scale depressions and the formation of outside overburden dumps. Due to the excavation process, depressions are created in the working cavities, and this causes changes and deterioration of the morphological and aesthetic characteristics of the existing natural landscape [26]. Considering that the character and the scope of mining works are such that the previous morphological appearance of the degraded areas cannot be restored, the obligation of a company is to adapt, in the best possible way, through the technological exploitation process, *i. e.* overburden disposal activities and technical reclamation, the working cavity to the existing natural environment, in terms of functionality and aesthetics.

Generally speaking, within the recultivation of deteriorated surfaces, it is necessary to apply [27]:

- technical measures – which contribute to the improvement of resistant and deformable characteristics of the dump and directly influence the enhancement of the erosion stability of slopes,
- biotechnical measures – which, along with the technical measures, contribute to faster achieving and maintaining the dump stability, and
- biological measures – which imply the implementation of agricultural and forest improvements that contribute to the stability and maintenance of reclaimed areas, but they are much more significant from the aspect of area revitalisation and establishing natural biocenoses.

Notwithstanding all the restructuring cases, a number of people will be superfluous. They will then be re-educated or they will leave, which is certainly a problem accompanying the mining industry. Favourable circumstances in the whole process of turning an agricultural terrain into an industrial one, which is reclaimed at a later stage, is the fact that this process is very slow and that good planning may adequately rearrange it. Depending on the size of the deposit, the process of turning an agricultural, forest, or urban environment into an industrial (mining) one, and then, by the recultivation process, back again into the agricultural or forest one, may be of different durations, but such processes often last for many decades. The unfavourable characteristic of this transformation process is that, due to its long duration, there is a high probability of the emergence of economic and social crises and negative flows.

Conclusions

“Coal is a crucial and enduring element in a modern, balanced energy portfolio, providing a bridge to the future as an important low cost and secure energy solution to sustainability challenges” [28]. The coal extraction in Kolubara coal basin may last for about 50 years, which is the corresponding amount of coal reserves. Namely, we shall spend the coal 10.000 times faster than it took it to be formed. It is certainly a great disturbance of the natural cycle of oxygen and CO₂ circulation. Sustainable development requires the maintenance, rational use, and enhancement of natural resources, as well as a balanced consideration of ecology, economy, and social justice [29].

There are plenty of arguments to prevent further expansion of the utilisation of fossil fuels and therefore coal [30]. This is one reason, among others, why it is necessary to perform the recultivation of a dump even though it has a relatively low, although favourable, impact on the environment. As we are talking about fertile alluvial lands, it is necessary to preserve the fertile soil layer through selective excavation in order to bring the soil back to its previous purpose – agricultural production. The forestation of soil and terrains deteriorated by open-cast lignite mining prevents further deterioration processes, contributes to the maintenance of the ecological balance in nature, and enhances the absorption of CO₂ from the air and the content of the oxygen therein.

Notwithstanding the fact that nature has efficient mechanisms for balancing and equilibrating the gas concentration in the air, it also has limited capacities in this process. We gave ourselves the right to use the coal, as it is suitable for us. Because of this, we have a great responsibility to do that in the best possible way, bearing in mind future generations, by utilising coal reserves in compliance with the principles of the sustainable development referring to the utilisation of non-renewable energy resources and by reclaiming deteriorated surfaces resulting

from the process of coal extraction, and all that in the function of sustainable development, mining exploitation, and utilisation of energy from nature.

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Applicability of Continuous Real-Time Monitoring Systems in Safety Assurance of Significant Structures

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In recent years, there has been significant advancement in monitoring sciences, especially due to the continued development of measuring equipment. Consequently, continuous real-time monitoring of integrity of significant structures, like buildings, bridges, dams, as well as the movement of slopes, landslides and volcanoes has become possible. This paper presents the usefulness of continuous real-time monitoring system that is able to combine geodetic, geotechnical and meteorological sensors to match the needs of the monitoring project. At the experimental polygon, we have installed four points; one reference and three observation points, all based on global navigation satellite system (GNSS) sensors. For every point, we acquire location in sense of coordinate Y, X and H in the local coordinate system, which allows observing any movements and deformations on observation points. Moreover, the characteristics of experimental polygon correspond to observing structures and also any changes on the Earth's surface. The real-time visualization of acquired data enables us to decide on further measures in the shortest possible time, which reflects in major safety, as well as in the avoidance of severe damage. On the basis of 20 minutes of measurements, executed every 24 hours, we have calculated that it is possible to detect, with a 99.73% probability, all displacements larger than 1.2 mm and relative movements larger than 3 mm. The monitoring results and regression lines indicate that displacements for two points are no more than 1 mm, while on one we have obtained displacement of approximately 7 mm in a time period of only three months. The results obtained are significant and confirm the necessity of continuous real-time monitoring systems.

Primjenjivost kontinuiranog monitoring sustava u realnom vremenu za održavanje sigurnosti važnih objekata

Izvorno znanstveni članak

U posljednjih nekoliko godina, došlo je do velikog napretka u znanosti o nadzoru (monitoringu), posebice zbog kontinuiranog razvoja mjerne opreme. Prema tome, kontinuirani real-time nadzor integriteta značajnih objekata, kao što su zgrade, mostovi, brane, pomicanje padina, klizišta i vulkana, postao je moguć. Ovaj rad opisuje korist kontinuiranog monitoring sustava u realnom vremenu koji omogućava kombiniranje geodetskih, geotehničkih i meteoroloških senzora kako bi se odgovorilo potrebama monitoringa. Na eksperimentalnom poligonu su instalirana četiri mjerna mjesta; jedna referentna i tri promatrane točke, a sve se zasniva na globalnom navigacijskom satelitskom sustavu (GNSS). Za svaku točku može se odrediti položaj u lokalnom koordinatnom (Y, X, H) sustavu koji omogućuje praćenje pomicanja i deformacija na mjernim mjestima. Štoviše, karakteristike eksperimentalnog poligona odgovaraju opažanim strukturama kao i bilo kakvim promjenama na površini Zemlje. Real-time vizualizaciju prikupljenih podataka omogućuje odlučivanje o daljnjim mjerama u najkraćem mogućem roku, što se odražava boljom zaštitom radi sigurnosti, kao i izbjegavanjem ozbiljnih šteta. Na temelju 20 minutnih mjerenja, koje se vrši 24 sata na dan, izračunato je da je moguće s 99,73 % vjerojatnosti otkriti sva pomicanja veća od 1,2 mm, a relativna pomicanja veća od 3 mm. Rezultati monitoringa i regresijska analiza pokazuju da pomicanja dvaju mjernih mjesta nisu veća od 1 mm, a za jedno mjesto je dobiven pomak od oko 7 mm u vremenskom periodu od samo tri mjeseca. Dobiveni rezultati su značajni i potvrđuju nužnost kontinuiranih real-time monitoring sustava.

Symbols/Oznake			
Y	- UTM coordinate in Y direction - UTM koordinata u Y smjeru	v	- residual - pogreška
X	- UTM coordinate in X direction - UTM koordinata u X smjeru	σ	- standard deviation - standardna devijacija
H	- UTM coordinate in elevation direction - UTM koordinata u smjeru visine	σ^2	- variance - varijanca
$\hat{Y}$	- the most probable UTM coordinate in Y direction - najvjerojatnija UTM koordinata u Y smjeru	CQ	- Coordinate Quality - kakvoća koordinate
$\hat{X}$	- the most probable UTM coordinate in X direction - najvjerojatnija UTM koordinata u X smjeru	Q	- diagonal elements of variance-covariance matrix - dijagonalni elementi matrice varijance-kovarijance
$\hat{H}$	- the most probable UTM coordinate in elevation direction - najvjerojatnija UTM koordinata u smjeru visine	$M_o = \sigma_o$	- unit weight standard deviation - srednja devijacija jedinice težine
r	- scale factor - mjerilo	K_{total}	- total annualized HRSG cost - ukupni godišnji trošak kotla utlizatora
h	- specific entalpy, kJ/kg - specifična entalpija	Indices/Indeksi	
n	- number of observations/days - broj opažanja/dana	day	- day - dan

1. Introduction

Human interference of any kind in the environment can affect the stress-strain relations governing in those areas, resulting in landslides and slope failures. Furthermore, the safety and vitality of significant structures have become important issues. Thus, measures for preventing structural collapses, slope failures and landslides are of great interest to engineers. However, the afore-mentioned disasters do not occur without warning. Due to the needfulness of relating information, continuous real-time monitoring is suitable for observation of variations in structures or land masses. Continuous monitoring is a very complex system, constituted from methodology, sensors, software and knowledge for data acquisition and processing. Monitoring as an activity does not have any influence on operational procedures and is non-destructive. Moreover, the cost of monitoring in comparison to the possible cost due to any disasters that can be prevented by it is negligible. Several recent deformation-monitoring studies have proven that this kind of control is suitable for the observation of variations in structures and their vicinity as well for mass movements [1]. Presented monitoring can be required for underground constructions and their influence on nearby structures (e.g. [2-3]), for monitoring deformations and deflections of bridges [4], water dams (e.g. [5-6]) and ground subsidence [7], as well as for monitoring slope stability and steep embankment in open pit-mines (e.g. [8-9]). Furthermore, monitoring is suitable for controlling the behaviour of landslides and volcanoes (e.g. [10-11]). A continuous real-time monitoring system

can be used also for structural health-monitoring purposes instead of conventional monitoring using accelerometers. Çelebi has showed that monitoring based on GNSS provides sufficiently accurate measurements of relative displacements, so that dynamic characteristics of the vibrating systems can be accurately identified [12].

The motivations for this work were: 1. the determination and presentation of events; deformations, movements in real-time, 2. to assure safety, 3. post-processing in order to assess some correlations between movements and other effects on the site such as temperature, water saturation, wind, blasting, quakes etc., 4. creating virtual sensors to better understand what is happening. The data acquired may be used for further computation, deformation analysis, predictive maintenance and of course alarming. One of the monitoring attributes is also to support decision-making. The essence of a continuous real-time monitoring system is to respond as quickly as possible, meaning that we can take the necessary steps to prevent some harmful events before the accuracy analyses are completed. Those accuracy analyses take time, which would usually result in late decision-making. Thus, decision-makers have to choose between alternative procedures (Figure 1): a) to perform accuracy analysis and lose valuable time or b) to decide on further actions on the basis of a visual diagram comparison. We speak in favour of the second option, since the warning can be given in time to evacuate personnel and equipment. However, without experiences in accuracy analyses, decision-making on a visual basis

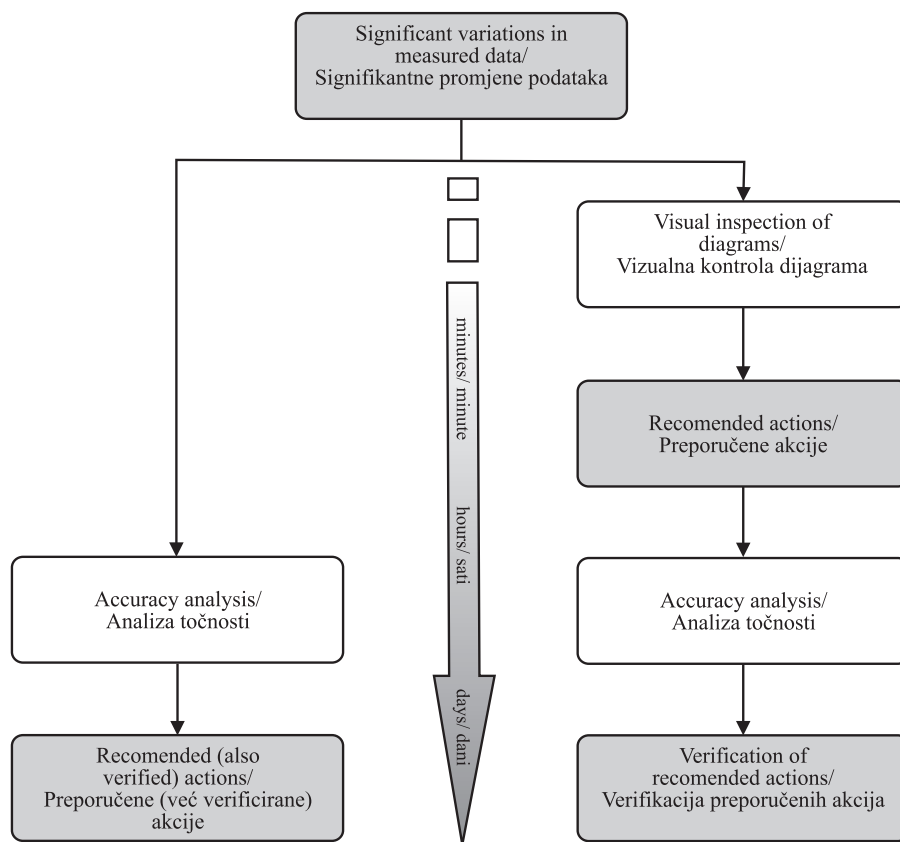


Figure 1. Decision procedures

Slika 1. Procedura odlučivanja

is delicate. Nevertheless post-festum analyses should be done to verify previous decisions, and for more accurate results.

2. Experimental monitoring system

The fundamental requirement of the continuous real-time GNSS based monitoring is that a permanent GNSS receiver must be located at each point so as to be monitored. The experimental continuous real-time monitoring system consists of four points; one stable/reference point, GRS1, and three observation object points, GMX1, GMX2 and GMX3 (Figure 2).

On the reference station, one dual frequency receiver and three single frequency receivers are installed on the observation points. In addition, the system is designed to enable the connection of various sensors. We have also included in the experimental monitoring system, two-axis inclinometers, along with the belonging thermometers, to follow the position of the tangential plane of the subsidence surface at measurement points. All points are also equipped with a battery power supply and a communication box for remote control and data delivery via the wireless communication network. The equipment installed and used is represented in Figure 3. We acquire coordinates Y , X and H in the local coordinate system for

every point, and for three observation points, also their inclinations in two directions. The reference point is used as an origin of vectors to observation points, from which the coordinates of the observation points are defined. Any kinds of change in size and/or direction of vectors signify the movements of observation points.

The time interval of registered measurements depends on the scope of monitoring and, in our case, the measurement interval could be set from 10, 30 or 60 minutes to 3, 6, 12 or 24 hours. Extremely short intervals of 1 sec or less have also been planned to be carried out. It should be mentioned that measurements at some defined time interval mean that not only one measurement but many are acquired inside that time interval, and the most representative of the measurements is then selected. Referred time intervals correspond to requirements of monitoring for different purposes [13]. For example, if our aim is to detect changes above tunnels or on water dams, the required measurement interval should be 10, 30 or maximum 60 minutes. In case of monitoring important structures such as power plants, power or water lines, this period should vary from 1 to 12 hours. When we deal with projects that do not involve fast changes or we do not need data delivered over short periods of time, such as open pit mines, stone-pits, constructions, the measurement periods could be increased to 12 or

24 hours. Generally speaking, the frequency of data acquisition should be experimentally adapted to the best-suited of observed processes.

3. Error analysis

A least squares adjustment is a well-known technique to process sets of redundant observations acquired with the GNSS. General results are the coordinates of measured points and their standard deviations. Any coordinate changes during some period signify point movement. In this paper, only error analysis calculations for 24 hour measurements will be presented in detail. For any other time intervals, the analysis is analogous.

3.1. Error analysis theory

In geodetic observations, the true position of any point is never known. The most probable point coordinates in case of redundant observations is simply the arithmetic mean [14]:

$$\hat{Y} = \frac{\sum_{day=1}^n Y_{day}}{n}, \quad (1)$$

$$\hat{X} = \frac{\sum_{day=1}^n X_{day}}{n}, \quad (2)$$

$$\hat{H} = \frac{\sum_{day=1}^n H_{day}}{n}, \quad (3)$$

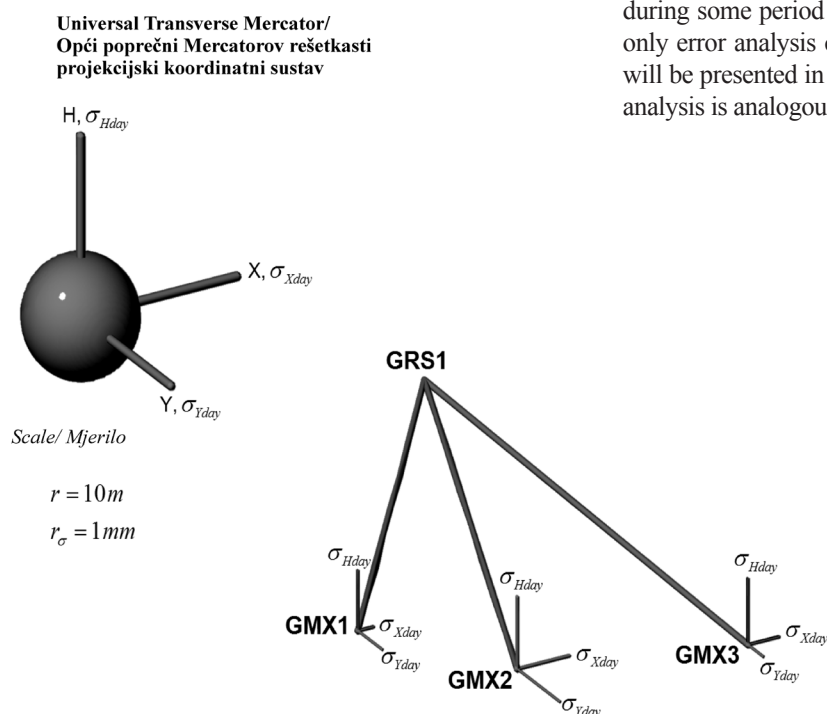


Figure 2. Scheme of the monitoring system

Slika 2. Shema monitoring sustava

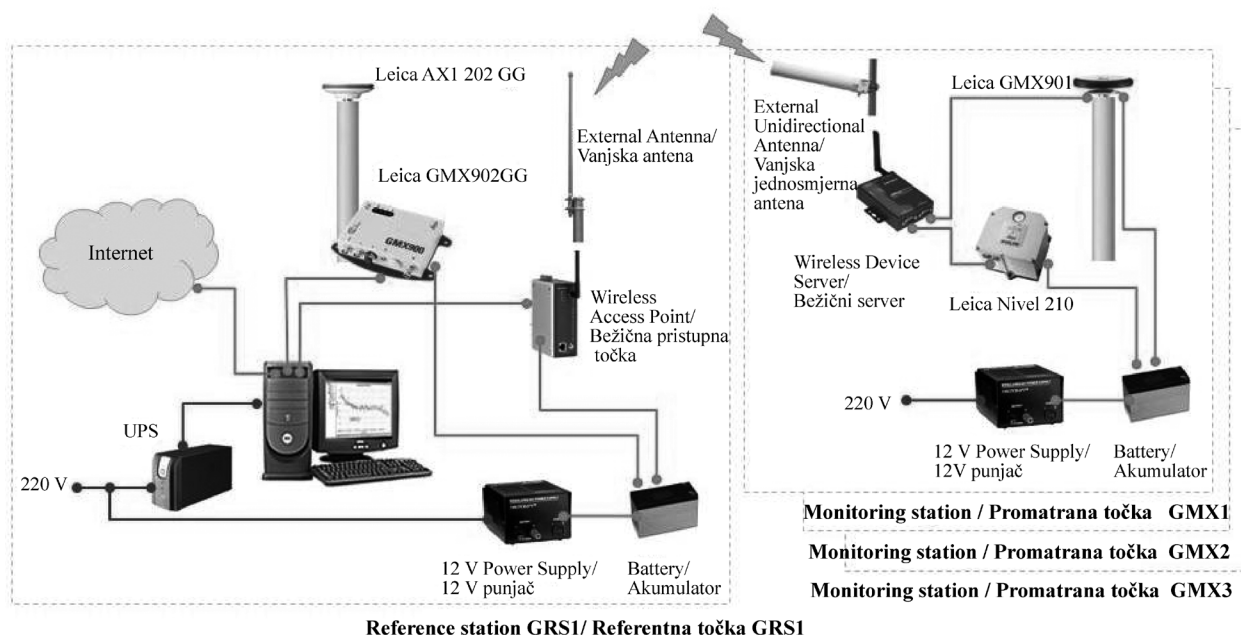


Figure 3. Equipment on reference and observation points (pictures from Leica catalogues)

Slika 3. Oprema na referentnoj i promatranoj točki (slike iz Leica kataloga)

where $\hat{Y}$, $\hat{X}$, $\hat{H}$ are the most probable coordinates, $\sum_{day=1}^n Y_{day}$, $\sum_{day=1}^n X_{day}$, $\sum_{day=1}^n H_{day}$ the sum of the individual measurements Y_{day} , X_{day} , H_{day} , and the n the total number of observations/days.

Furthermore, the residuals are calculated as:

$$v_{Yday} = Y_{day} - \hat{Y}, \quad (4)$$

$$v_{Xday} = X_{day} - \hat{X}, \quad (5)$$

$$v_{Hday} = H_{day} - \hat{H}, \quad (6)$$

and standard deviations as:

$$\sigma_{Yday} = \sqrt{\frac{\sum_{day=1}^n v_{Yday}^2}{n-1}}, \quad (7)$$

$$\sigma_{Xday} = \sqrt{\frac{\sum_{day=1}^n v_{Xday}^2}{n-1}}, \quad (8)$$

$$\sigma_{Hday} = \sqrt{\frac{\sum_{day=1}^n v_{Hday}^2}{n-1}}, \quad (9)$$

where σ_{Yday} , σ_{Xday} , σ_{Hday} is the standard deviation of a group of observations of the same quantity (point coordinates Y , X or H), v_{Yday} , v_{Xday} , v_{Hday} the residual of an individual observation, $\sum_{day=1}^n v_{Yday}^2$, $\sum_{day=1}^n v_{Xday}^2$, $\sum_{day=1}^n v_{Hday}^2$ the sum of squares of the individual residuals, and n the number of observations/days. Variances are equal to σ_{Yday}^2 , σ_{Xday}^2 , σ_{Hday}^2 the square of the standard deviations.

In practice, we often want to estimate unknown coordinates based on one or more series of observations. The sample mean $\hat{Y}$, $\hat{X}$, $\hat{H}$ are standard estimates of v_{Yday} , v_{Xday} , v_{Hday} [15-16].

$$\sigma_{\hat{Y}} = \sqrt{\frac{\sigma_{Yday}^2}{n}}, \quad (10)$$

$$\sigma_{\hat{X}} = \sqrt{\frac{\sigma_{Xday}^2}{n}}, \quad (11)$$

$$\sigma_{\hat{H}} = \sqrt{\frac{\sigma_{Hday}^2}{n}}. \quad (12)$$

3.2. Error analysis results

For analysis, the positions refer to a local coordinate system. A transformation must be carried out to convert the positions delivered in the GNSS UTM frame into the local system (Figure 2). Here, the presented error analysis results are based on 10 minute and 24 hour measurement time intervals.

For observation points GMX1, GMX2 and GMX3, the results address a total period of 136, 119 and 151 days, respectively. The corresponding results for a 24 hour time interval are shown in Table 1.

Table 1. Error analysis results for a 24 hour time interval on observation points GMX1, GMX2 and GMX3

Tablica 1. Rezultat analize pogrešaka za interval od 24 sata na mjernim točkama GMX1, GMX2 i GMX3

Point / Točka	GMX1	GMX2	GMX3
n	136	119	151
σ_{Xday} , m	0.0003	0.0010	0.0006
σ_{Yday} , m	0.0008	0.0014	0.0005
σ_{Hday} , m	0.0010	0.0012	0.0011
$\sigma_{\hat{Y}}$, m	0.0000	0.0001	0.0001
$\sigma_{\hat{X}}$, m	0.0001	0.0001	0.0000
$\sigma_{\hat{H}}$, m	0.0001	0.0001	0.0001
$\hat{X}$, m	3413.894	3427.574	3465.288
$\hat{Y}$, m	8834.659	8805.291	8793.635
$\hat{H}$, m	453.731	455.675	455.777

The analysis of a 10 minute interval measurements was performed as well. The results are shown in Table 2. Note that incomplete measurements were eliminated from the analysis. We considered only measurements that correspond to the criteria of 60 % of realised observations in a period of a day.

Among other parameters, Leica's instruments also yield the Coordinate Quality (CQ) parameter. The CQ parameter is based on the standard deviation, but additionally, empirical assumptions about environmental conditions are also taken into consideration. The CQ is derived so that there is at least two thirds of a probability that the computed position deviates from the true position by less than the CQ value [17], [18].

$$CQ = M_0 \sqrt{Q_{11} + Q_{22} + Q_{33}} \quad M_0 = \sigma_0. \quad (13)$$

Table 2. Error analysis results for a 10 minute time interval on observation points GMX1, GMX2 and GMX3**Tablica 2.** Rezultat analize pogrešaka za interval od 10 minuta na mjernim točkama GMX1, GMX2 i GMX3

Point / Točka	GMX1		GMX2		GMX3	
	min	max	min	max	min	max
$\sigma_{\hat{X}_P}$, m	0.0012	0.0456	0.0011	0.0343	0.0027	0.0402
$\sigma_{\hat{Y}_P}$, m	0.0019	0.0125	0.0015	0.0111	0.0031	0.0162
$\sigma_{\hat{H}_P}$, m	0.0031	0.0293	0.0026	0.0193	0.0057	0.0257
$\sigma_{\hat{Y}}$, m	0.0001	0.0038	0.0001	0.0022	0.0002	0.0034
$\sigma_{\hat{X}}$, m	0.0002	0.0011	0.0001	0.0009	0.0003	0.0013
$\sigma_{\hat{H}}$, m	0.0003	0.0024	0.0002	0.0012	0.0005	0.0023
$\hat{X}$, m	3413.886	3413.897	3427.564	3427.576	3464.781	3465.291
$\hat{Y}$, m	8834.636	8834.660	8805.243	8805.294	8793.623	8793.637
$\hat{H}$, m	453.728	453.735	455.672	455.677	455.677	455.778
n #	89	144	90	144	89	144

In Table 3, CQ values for observation points GMX1, GMX2 and GMX3 are depicted, which all correspond well with the mean standard deviations $\sigma_{\hat{X}}$, $\sigma_{\hat{Y}}$ and $\sigma_{\hat{H}}$ from Table 1.

Table 3. Coordinate Quality (CQ) values for GMX1, GMX2, and GMX3**Tablica 3.** Vrijednosti kakovoće koordinata (CQ) za GMX1, GMX2, i GMX3

Point / Točka		GMX1	GMX2	GMX3
CQ, m	min	0.0001	0.0001	0.0001
	max	0.0001	0.0001	0.0002

The presented error analysis deals with point coordinate estimations and their standard deviations. For long period measurements, the obtained accuracy is below 1 mm (Tables 1-3). Further calculations can include analyses of gross errors, data snooping, global test, all of which can be found in literature (for example [19]).

4. Visualisation as a quick method for decision making

Continuous real-time monitoring enables a rapid and proper response to time-critical emergencies, such as mass movements or a loss of structural integrity. As evident from Figure 1, a lot of valuable time can be preserved if we make a first decision on the basis of visual inspection and comparison of diagrams, which would be most welcome when potentially hazardous situations occur. For example, the diagrams on Figure 4 show the observation point coordinates variations in time from the experimental polygon for approximately three months, sampled with 24 hour intervals. With ellipse marks on diagrams, the simultaneous changes on all observation

points at the same time are shown, which indicate that this event is due to an external influence, perhaps errors on the data-acquisition device during on-the-fly calculations, satellite constellations, meteorological conditions. If we compare the final displacement values (arrows on Figure 4) of points GMX1, GMX2 and GMX3, it is evident that point GMX2 (marked with darker arrows) is steadily shifting (consider the trend of coordinates change), which is evident through visual inspection only.

Regression analysis (accomplished by common software) is an effective method to quickly explore the relationships between point variations and potential point movements [20], [21]. In particular, the real-time visualisation of regression lines for the observation points data allows users to decide whether observing variations indicate movement points or not, and without executing error analysis. Regression lines that correspond to point GMX1, GMX2 and GMX3 variations are shown in Figures 5, 6 and 7. Figure 5 (above) shows point GMX1 displacement values in main coordinate directions (N – North, E – East, H – Height) and corresponding regression lines. It is evident that regression lines are within the accuracy of the monitoring system (variations less than 1 mm) and thus indicate that point GMX1 is stable. Furthermore, the latter is even more obvious when we look at the diagram and corresponding regression line of the total displacement of point GMX1 (Figure 5 (below)).

The diagrams of point GMX2 observation data indicate the point movement in a north-east direction, namely in north, east and height coordinate axes direction for approximately 4 mm, 5mm and 2 mm, respectively (Figure 6 (above)). According to the total displacement regression line of point GMX2, the point had moved by approximately 7 mm in the period of three months (Figure 6 (below)).

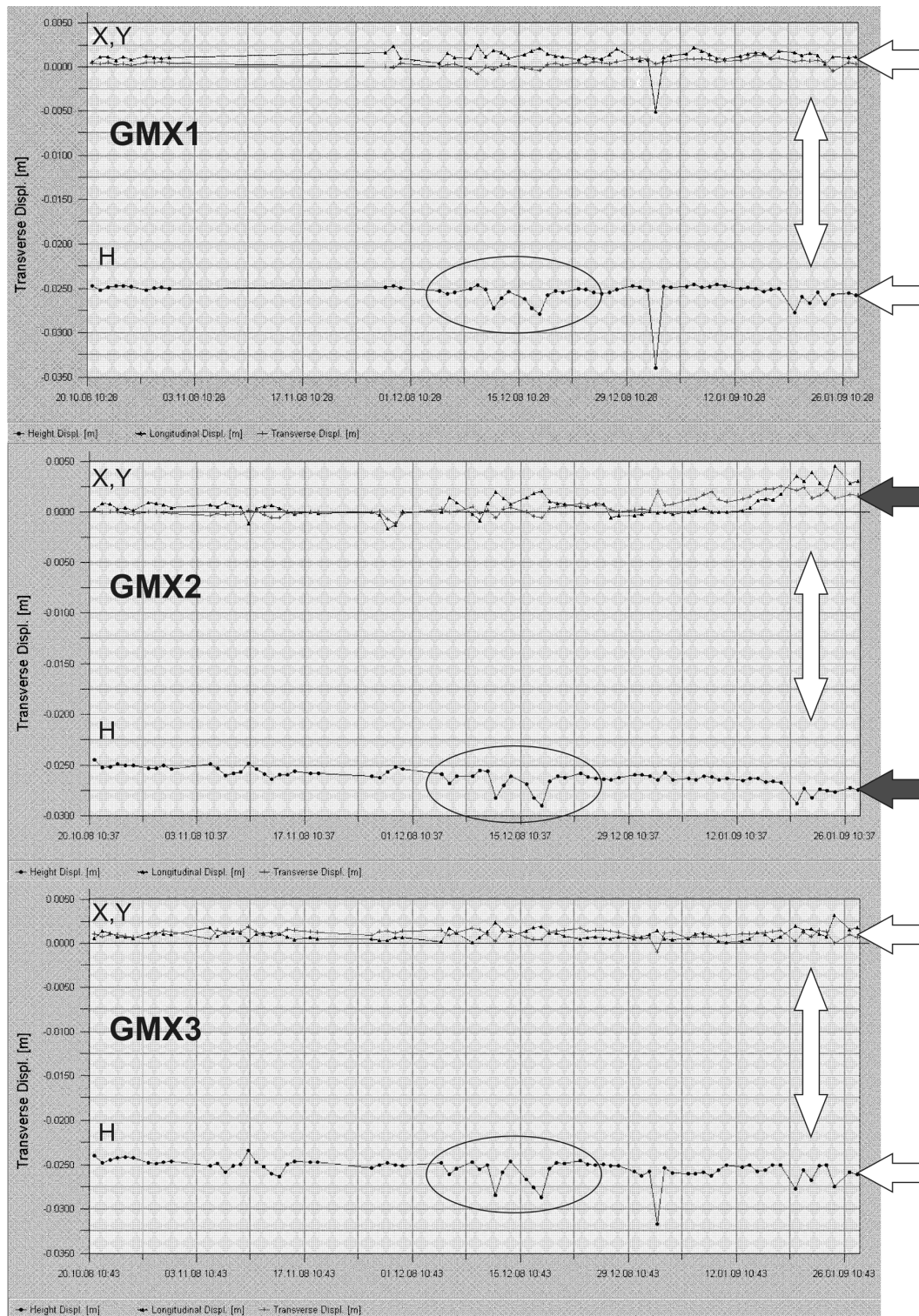


Figure 4. Point displacement real-time diagrams for observation points GMX1, GMX2 and GMX3

Slika 4. Real-time dijagram pomjeranja promatranih točaka GMX1, GMX2 i GMX3

Variations on observation point GMX3 are shown on Figure 7. Regression line values are within the monitoring system accuracy (variations less than 1 mm) and thus there is no indication of significant changes on point GMX3.

The trends of regression lines can be visually observed by users, but the quantitative values of the point

movements need to be further examined by detailed error analyses to verify preliminary decisions based only on visual inspection. The calculated displacement of GMX2 is approximately 7 mm in 3 months, which is a significant change as to σ_{day} . For the remaining two points, calculated displacements are approximately 1 mm, and so far both points are determined as stable.

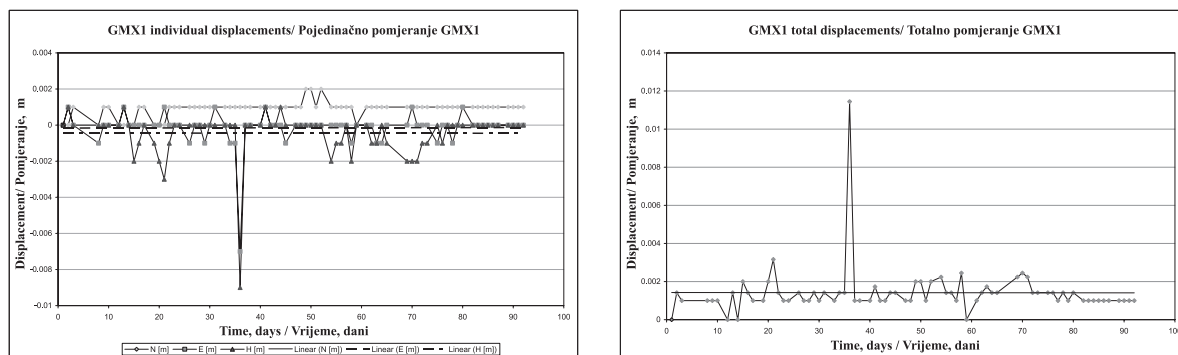


Figure 5. GMX1 point displacements and regression lines; Individual displacements according to coordinate axis directions and their regression lines (left), Total displacement and corresponding regression line (right)

Slika 5. Pomjeranja točke GMX1 i regresijski pravci; Pojedina pomjeranja u smjeru koordinatnih osi i odgovarajući regresijski pravci (lijevo), Totalni pomak i odgovarajući regresijski pravac (desno)

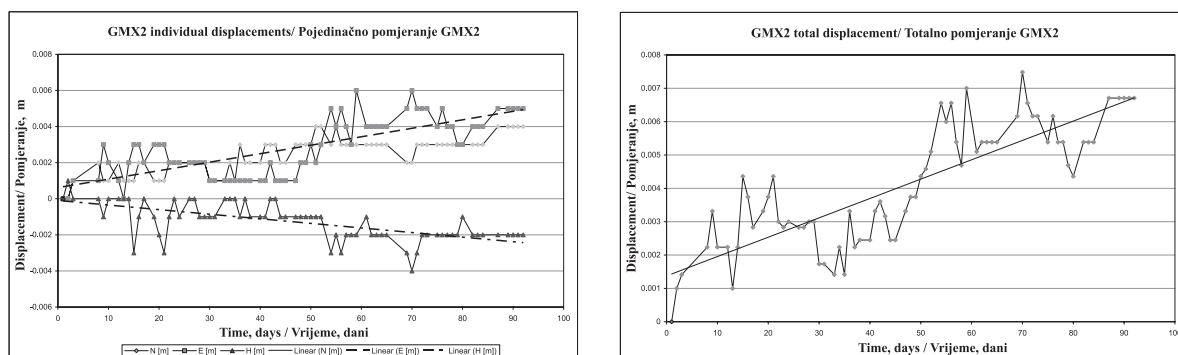


Figure 6. GMX2 point displacements and regression lines; Individual displacements according to coordinate axis directions and their regression lines (left), Total displacement and corresponding regression line (right)

Slika 6. Pomjeranja točke GMX2 i regresijski pravci; Pojedina pomjeranja u smjeru koordinatnih osi i odgovarajući regresijski pravci (lijevo), Totalni pomak i odgovarajući regresijski pravac (desno)

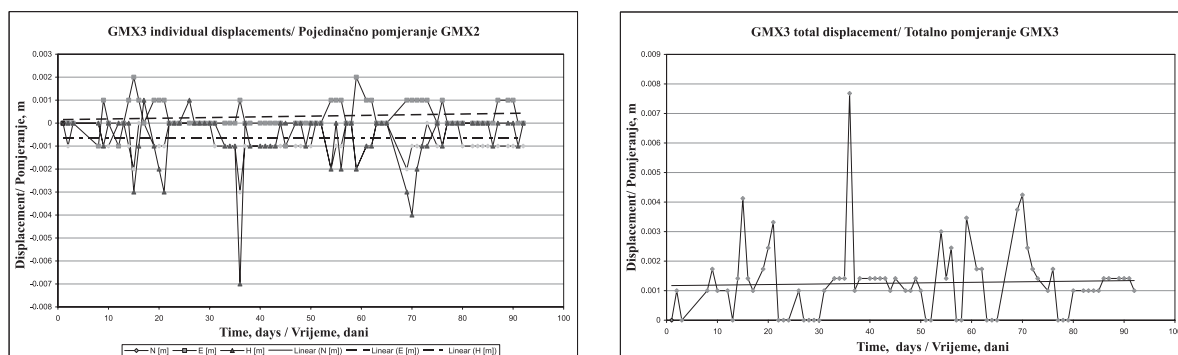


Figure 7. GMX3 point displacements and regression lines; Individual displacements according to coordinate axis directions and their regression lines (left), Total displacement and corresponding regression line (right)

Slika 7. Pomjeranja točke GMX3 i regresijski pravci; Pojedina pomjeranja u smjeru koordinatnih osi i odgovarajući regresijski pravci (lijevo), Totalni pomak i odgovarajući regresijski pravac (desno)

5. Conclusions

GNSS-based monitoring solutions are an important measuring tool to observe the movements and deformations of significant structures and the Earth's surface. The accuracy of such measurements depends on various factors, including sampling frequency, time intervals, satellite constellation, multipath. However, on the basis of 20 minutes of measurements on every 24 hours, we have calculated that the standard deviation of the monitoring system described in this paper is 0.1 to 0.5 mm and therefore allows us to detect displacements larger than 1.2 mm and relative movements larger than 3 mm, both with a 99.73 % probability. Obtained accuracy values are better than that provided by the manufacturer (Table 4). These findings refer only to the GNSS measurements. So as to achieve an even higher accuracy, the monitoring system can be spread out into a robotised total station and/or level (for example [22]).

Through comparison between standard deviations for 10 minute observations within a day ($\sigma_{\dot{x}}$, $\sigma_{\dot{y}}$, $\sigma_{\dot{h}}$) and standard deviations for 24 hour observations (σ_{xday} , σ_{yday} , σ_{hday}), it is clear that the values agree with one another well. The values range from 0.1 mm to 3.8 mm (Table 1 and Table 2) and are within the expected accuracy. Furthermore, this proves that observations conducted every 24 hours fulfil the monitoring requirements for projects that do not involve fast changes. For more delicate and critical projects, the observation interval should be shortened. If we compare Coordinate Quality (CQ) values for GMX1, GMX2, and GMX3 with standard deviations, it can be seen that CQ values are reliable for long period measurements. Observation points GMX1 and GMX3 are determined as stable, since the corresponding regression lines in the diagrams are almost horizontal (Figure 5 and 7). The calculated displacements for GMX1 and GMX3 are no more than 1 mm. Most significant displacement of approximately 7 mm were observed on point GMX2, which is evident through regression lines (Figure 6) and later on also supported by calculations.

Table 4. Leica GNSS sensor accuracy [23]

Tablica 4. Točnost Leica GNSS senzora [23]

Sensor type / Vrsta senzora	Time interval / Vremenski interval	2D accuracy / 2D preciznost (95 %)	Height accuracy / Visinska preciznost (95 %)
Dual-frequency (GMX902)	10 min	5.2 mm	11.8 mm
	1 h	3.8 mm	7.2 mm
	24 h	1.8 mm	2.0 mm
Single-frequency (GMX901)	10 min	7.2 mm	12.4 mm
	1 h	3.8 mm	7.0 mm
	24 h	2.2 mm	1.8 mm

The continuous real-time monitoring system presented through this article has many benefits; we gain the greatest quantity of data per unit of time, employing the least of engaged resources, we obtain information in real-time and thus react immediately to solve potentially hazardous situations, the system allows a plug-in of a very large number of different types of sensors so as to adjust to the specific process characteristics, and it offers greater accuracy than other surveying techniques. Through real-time monitoring of important structures, abnormal behaviour can be detected and, therefore, it is possible to avoid severe damage or even save lives.

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Parametric adjustment of a junction triangle in terms of the precise construction of haulage drives in underground mines

Nivelamento indireito do triângulo de conexão em função de escolha de vias ótimas de transporte em minas subterrâneas

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Resumo

Nos custos totais de exploração de matérias-primas minerais, o transporte participa com 30-60%, o número total de empregados no transporte excede 35%, enquanto o consumo total de energia para o transporte na mina é acima de 40%. Todos esses valores mostram que o transporte representa um dos processos tecnológicos mais importantes na exploração subterrânea de matérias-primas minerais e que a questão de transporte é muito importante, como na escolha do tipo de sistema de transportação, como também na sua projeção, exploração e manutenção. A eficiência do transporte, além de muitos parâmetros técnicos e tecnológicos de exploração, como também de condições mineiro-geológicas, depende, também, da escolha de vias de transporte ótimas, que, se conseguem através de conexão exata de locais subterrâneos de minas com pontos da rede mineira na superfície do terreno. A escolha de vias ótimas de transporte mineiro representa uma das tarefas mais importantes nas medições mineiras. Essa obra mostra a maneira de nivelamento indireito do triângulo de conexão em fossa através de método de nivelamento indireito.

Palavras-chave: Medições mineiras, transporte, conexão, triângulo de conexão, nivelamento indireito.

Abstract

In total costs of ore mining, haulage participates with 30-60%; the total number of workers engaged in the transportation exceeds 35%, while the participation of transportation in the total power consumption amounts to over 40%. All these values indicate that transportation is one of the most significant challenges in the underground mining of ore deposits and that haulage analysis is very important both in selecting the haulage type and its design, utilization and maintenance. In addition to various technical mining parameters, together with mining and geological conditions, haulage efficiency depends on the selection of optimal haulage drives, which can be achieved by accurately connecting the underground mine workings with mine network points on the surface of a site. The selection of the best mine haulage routes is one the most critical tasks in mine surveying. This paper shows how to adjust a junction triangle on a working level using the parametric adjustment method.

Keywords: Mine surveying, underground mine haulage, junction triangle, parametric adjustment.

1. Introduction

Combined haulage systems (railway transport - hoisting shaft) are the most applied systems in underground mines, both in Serbia and in the nearby countries. Connecting the underground mining workings is an important part of haulage design due to the fact that all the subsequent works follow the connection results, and therefore their accuracy depends largely on the accuracy of the connecting procedure (Ristic, 2006). One of the most applied connection methods through a vertical shaft is the Weisbach or "junction triangle method" (Figure 1). The usual adjustment procedure for junction triangles is based on the conditional adjustment method.

The objective of the connecting procedure is to connect the stopes and the underground workings of a mine, or the related working level of a mine, with the site surface. More accurately, the connecting procedure determines the horizontal coordinates of the working level of the mine within the same reference system of the surface topography.

The connection through mine workings can be carried out regardless of its position in space, but the most difficult and the most complex connecting procedure is the one established through vertical workings (Vižintin et al., 2008). In such a case, two plumb lines are projected through the mine's main shaft to represent a straight, vertical line. Therefore, the X and Y coordinates of the plumb lines in the surface will be the same as of the underground working level of the mine. By creating various geometrical figures and by measuring angular and length values, on the basis of known coordinates of the plumb lines, the coordinates of the first point and the direction angle of the first side of a future underground theodolite traverse are calculated, which is the objective of connecting.

2. Connecting by the junction triangle method

In connecting main mine galleries through one vertical shaft, the Weisbach method is mostly used, which is also

known as the Junction triangle method. Vertical plumb lines in the shaft with the given point beside the shaft on the surface of the site, and with an unknown point on the mine level form two linked triangles having one common side - the side between the plumb lines. In these triangles, all of the three sides and the angle against the side between the plumb lines are measured, and it is a common practice that, due to a lower impact of errors of length measuring, the triangles are oblique ($\alpha < 20^\circ$; $\beta > 160^\circ$) (Borshch-Komponiets et al., 1989). When dealing with oblique triangles like the latter, the unknown angles α and β are calculated by applying the *Sinus theorem*. Four values are measured in each triangle, i.e. one more measurement per each triangle is available, which enables the measurement results to be included in the process of strict adjustment. However, most technical journals tend to emphasize the adjustment of non-oblong junction triangles. The reason for the "non-adjustment" of oblong junction triangles is because the measurements carried out therein are more accurate, and therefore there are no significant differences between the approximate and adjusted coordinates of the points on the working mine level. Hence, the adjustment process becomes more complex, and more comprehensive, requiring longer measurements which may increase the possibility of errors. However, if these were compelling arguments once, now such a concept is completely surpassed (Ganic & Djordjevic, 1999).

The adjustment of junction triangles is currently carried out via the conditional adjustment method, where, because of one redundant measurement per triangle, there is one conditional equation for each triangle, both on the site surface and on the working mine level. However, professional papers have never presented this possibility and the application of the parametric adjustment of a junction triangle on a working mine level. Parametric and conditional adjustment are based on the total least-squares method (Golub & Van Loan, 1996). For this reason, these two ways of calculation will give the same final results (Blaha, 1984). Nevertheless, due to its advantages, the parametric adjustment is applied more frequently than the conditional adjustment.

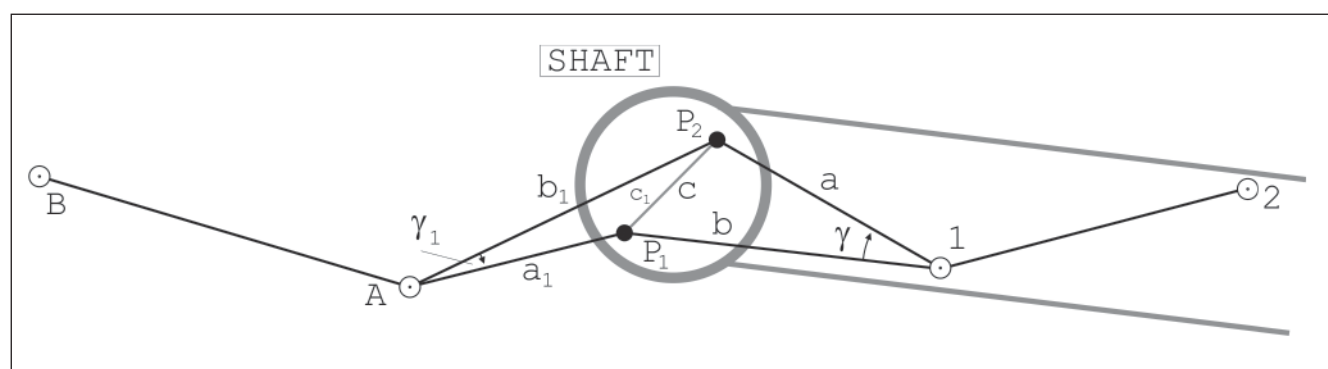


Figure 1 - Connecting procedure by the Weisbach method (junction triangle method).

3. Parametric adjustment of a junction triangle

The parametric adjustment has been applied to a junction triangle taking into account measurements on a working mine level, as follows:

- 3 measured horizontal directions from an unknown point 1 ($\alpha_1, \alpha_2, \alpha_3$).
- 3 measured horizontal lengths from point 1 towards an unknown point 2 on the working mine level (d_1) and towards plumb lines (d_2, d_3). The length between the plumb lines on the working mine level is measured for the purpose of the known measurement accuracy control ($|c - c_r| \leq 3mm$), but it is not included in the adjustment process.

The given adjustment data are the coordinates of the plumb lines P_1 and P_2 , calculated on the basis of the measurements on the surface of the site. It is also necessary to determine the approximate coordinates of the unknown points 1 and 2 on the working mine level.

In the parametric adjustment of working mine level measurements, there are six measured values available, and five unknown values, namely: Y and X coordinates of the points 1 and 2 and the definite angle for the orientation of the observed horizontal directions from point 1 (Hu & Tang, 2001).

In the parametric adjustment, it is necessary to establish functional connections among measured values and unknown variables, based on which residual equations are created (Aleksic, 1990; Strang & Borre, 1997, Fan & Yao, 2005). The residual equations are then converted into standard equations, which are solved in increments, resulting in this case on the coordinates of the unknown points 1 and 2 on the working mine level.

3.1 Residual equations for the measured horizontal directions

The functional relation for the measured horizontal directions is as follows:

$$\alpha_{si} + v_{\alpha si} = v_{si} + z_s \quad (1)$$

Where:

α_{si} - Measured horizontal directions from the station S towards the points 1, 2,... i .

$v_{\alpha si}$ - Residuals of the corresponding horizontal directions.

v_{si} - Direction angles from the point S towards the points 1, 2,... i .

z_s - Angle for the orientation of horizontal directions measured from the station S .

If the unknown direction angles and the orientation angle are expressed through approximate values and corresponding increments such as:

$$v_{si} = n_{si} + \delta v_{si} \quad (2)$$

$$z_s = z_s^\circ + \delta z_s \quad (3)$$

Then, the approximate values of the unknowns are calculated according to the following equations:

$$n_{si} = \arctan \frac{Y_i^\circ - Y_s^\circ}{X_i^\circ - X_s^\circ} \quad (4)$$

$$z_s^\circ = \alpha_{si} - n_{si} \quad (5)$$

Equation (1) can also be expressed as:

$$\alpha_{si} + v_{\alpha si} = \arctan \frac{Y_i^\circ - Y_s^\circ}{X_i^\circ - X_s^\circ} + \delta v_{si} + z_s^\circ + \delta z_s = F(X_s^\circ, Y_s^\circ, z_s^\circ, X_i^\circ, Y_i^\circ) \quad (6)$$

By linearization of (6), we obtain:

$$v_{\alpha si} = \frac{\partial F}{\partial X_s^\circ} \delta X_s + \frac{\partial F}{\partial Y_s^\circ} \delta Y_s + \frac{\partial F}{\partial X_i^\circ} \delta X_i + \frac{\partial F}{\partial Y_i^\circ} \delta Y_i + \frac{\partial F}{\partial z_s^\circ} \delta z_s + f_{\alpha si} \quad (7)$$

That is, the final residual equations are in the form of:

$$v_{\alpha si} = a_{si} \delta X_s + b_{si} \delta Y_s + a_{is} \delta X_i + b_{is} \delta Y_i + c_s \delta z_s + f_{\alpha si} \quad (8)$$

Where the coefficients are:

$$a_{si} = \frac{\partial F}{\partial X_s^\circ} = \frac{\sin n_{si}}{s_{si}} \cdot \rho'' \quad a_{is} = \frac{\partial F}{\partial X_i^\circ} = -a_{si}$$

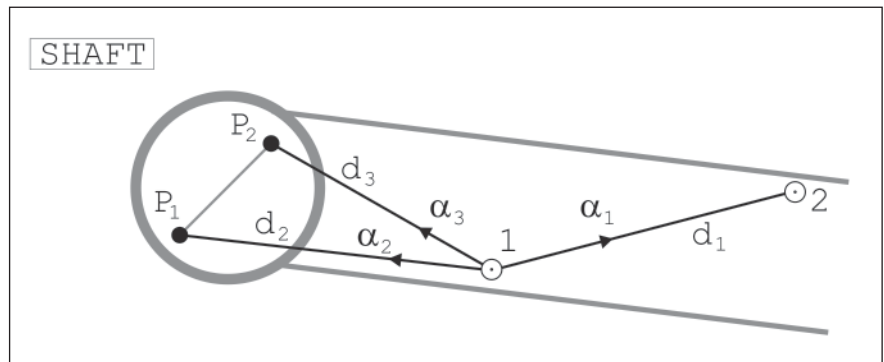


Figure 2 - Measured values in a junction triangle on a working mine level.

$$b_{si} = \frac{\partial F}{\partial Y_s^\circ} = -\frac{\cos n_{si}}{s_{si}} \cdot \rho'' \quad b_{is} = \frac{\partial F}{\partial Y_i^\circ} = -b_{si}$$

$$c_s = \frac{\partial F}{\partial z_s^\circ} = +1$$

And the free elements are:

$$f_{\alpha_{si}} = n_{si} + z_s^\circ - \alpha_{si}$$

The final set of equations (8) refers to horizontal directions perceived between two unknown points. For directions perceived from an unknown point towards the given points, the increments are as follows:

$$\delta X_i = 0; \delta Y_i = 0$$

So the residual equations are:

$$v_{\alpha_{si}} = a_{si} \delta X_s + b_{si} \delta Y_s + c_s \delta z_s + f_{\alpha_{si}} \quad (9)$$

3.2 Residual equations for measured horizontal lengths

The functional relation for measured horizontal lengths is as follows:

$$d_{si} + v_{d_{si}} = d_{si}' \quad (10)$$

Where:

d_{si} - Measured horizontal lengths between the point S and points 1, 2,... i;

$v_{d_{si}}$ - Residuals of corresponding horizontal lengths;

d_{si}' - Adjusted values of horizontal lengths.

If in equation (10), the most probable length values are replaced by approximate values and their corresponding increments, this equation becomes:

$$d_{si} + v_{d_{si}} = d_{si}^\circ + \delta d_{si} \quad (11)$$

Whereby the approximate lengths are calculated on the basis of approximate coordinates of the points, according to the equation:

$$d_{li}^\circ = \sqrt{(Y_i^\circ - Y_1^\circ)^2 + (X_i^\circ - X_1^\circ)^2} \quad (12)$$

Therefore, equation (11), becomes:

$$d_{si} + v_{d_{si}} = \sqrt{(Y_i^\circ - Y_s^\circ)^2 + (X_i^\circ - X_s^\circ)^2} + \delta d_{si} = F(X_s^\circ, Y_s^\circ, X_i^\circ, Y_i^\circ) \quad (13)$$

By linearization of the equation (13):

$$v_{d_{si}} = \frac{\partial F}{\partial X_s^\circ} \delta X_s + \frac{\partial F}{\partial Y_s^\circ} \delta Y_s + \frac{\partial F}{\partial X_i^\circ} \delta X_i + \frac{\partial F}{\partial Y_i^\circ} \delta Y_i + f_{d_{si}} \quad (14)$$

We obtain the final residual equations for the measured horizontal lengths:

$$v_{d_{si}} = A_{si} \delta X_s + B_{si} \delta Y_s + A_{is} \delta X_i + B_{is} \delta Y_i + f_{d_{si}} \quad (15)$$

Where the coefficients are:

$$A_{si} = \frac{\partial F}{\partial X_s^\circ} = -\cos n_{si} \quad A_{is} = \frac{\partial F}{\partial X_i^\circ} = -A_{si}$$

$$B_{si} = \frac{\partial F}{\partial Y_s^o} = -\sin n_{si} \quad B_{is} = \frac{\partial F}{\partial Y_i^o} = -B_{si}$$

And the free elements are:

$$f_{d_{si}} = d_{si}^o - d_{si}$$

The same applies to final residual equations for measured directions; equation (15) refers to the measured lengths between an unknown point and the given ones and the final residual equations are in the following form:

$$v_{d_{si}} = A_{si} \delta X_s + B_{si} \delta Y_s + f_{d_{si}} \quad (16)$$

3.3 Final residual equations for the parametric adjustment of a junction triangle in a working mine level

Taking into account Figure 2 and the equations (8), (9), (15) and (16), the residual equations in the parametric adjustment of measurements in a junction triangle on a working mine level are as follows:

$$\begin{aligned} v_{\alpha_1} &= a_{1,2} \delta X_1 + b_{1,2} \delta Y_1 + a_{2,1} \delta X_2 + b_{2,1} \delta Y_2 + \delta z_1 + (z_1^o + n_{1,2} - \alpha_1) \\ v_{\alpha_2} &= a_{1,1} \delta X_1 + b_{1,1} \delta Y_1 + \delta z_1 + (z_1^o + n_{1,1} - \alpha_2) \\ v_{\alpha_3} &= a_{1,v_2} \delta X_1 + b_{1,v_2} \delta Y_1 + \delta z_1 + (z_1^o + n_{1,v_2} - \alpha_3) \\ v_{d_1} &= A_{1,2} \delta X_1 + B_{1,2} \delta Y_1 + A_{2,1} \delta X_2 + B_{2,1} \delta Y_2 + (d_{1,2}^o - d_{1,2}) \\ v_{d_2} &= A_{1,v_1} \delta X_1 + B_{1,v_1} \delta Y_1 + (d_{1,v_1}^o - d_{1,v_1}) \\ v_{d_3} &= A_{1,v_2} \delta X_1 + B_{1,v_2} \delta Y_1 + (d_{1,v_2}^o - d_{1,v_2}) \end{aligned} \quad (17)$$

In accordance with the final set of residual equations (17), the coefficient matrix of error equations, the free element vector, and the weight matrix, based on standard deviations to the measured directions and lengths are created. Then, the parametric adjustment is carried out according to the known equations, whereby both the coordinates and their increments of the unknown points on the working mine level are obtained according to the equations:

$$Y_1 = Y_1^o + \delta Y_1; \quad X_1 = X_1^o + \delta X_1 \quad Y_2 = Y_2^o + \delta Y_2; \quad X_2 = X_2^o + \delta X_2 \quad (18)$$

This solution properly addresses the issue of the parametric adjustment of a junction triangle on the working mine level.

4. Connecting a haulage gallery in the coal mine Soko by applying the parametric adjustment of a junction triangle

Soko's Brown Coal Mine has one haulage shaft and one ventilation shaft, both 160 m deep. Mine development has been carried out through a series of slopes and horizontal galleries. The haulage shaft was subsequently deepened for another 100m, taking its total depth to 260m. New drives were also constructed (GTN-1 and GTN-2) to enable access to the Eastern limb of the Central field. The mining method in the Soko Mine is a variant of the room-and-pillar method, with the construction of level drives alongside the seam, with roof coal slicing in retreat. Production is carried out simultaneously through two level drives.

Figures 3, 4 and 5 show geological cross sections through the main underground workings of the Central Field Eastern Limb, in Soko's Brown Coal Mine.

The solution of opening the Eastern Limb of the Central Field is based on the division of a mineable deposit into two levels. The first level is located at elevation -44m to provide working access to the Western and Central fields above such elevation. The second level is projected at elevation -150m in order to provide access to the Central field between the first and the second levels. The opening of the -44m level was envisaged to be carried out in two stages. The first stage includes the construction of the main access from the surface to the bottom of the haulage shaft as well as ventilation, haulage and other operating conditions necessary for the continuation of works. The general layout of the working drives of such arrangement is shown in Figure 6.

The connection of the working drives shown in Figure 6 has been carried out using the junction triangle method. Two plumb-bobs, with horizontal coordinates defined by the intersections, were suspended from the surface down to one of the haulage drives. The following measurements were taken within the haulage drive:

- Three sets of angular measurements by theodolite Wild T2.
- Ten repetitions of length measurements by a precise steel band.

The proposed procedure for the parametric adjustment of the junction triangle is:

- Coordinates of the plumb lines P_1 and P_2 obtained on the basis of the measurements on the surface:

$$\begin{aligned} Y_{P_1} &= 660.3738m & X_{P_1} &= 812.7780m \\ Y_{P_2} &= 662.6494m & X_{P_2} &= 812.6890m \end{aligned}$$

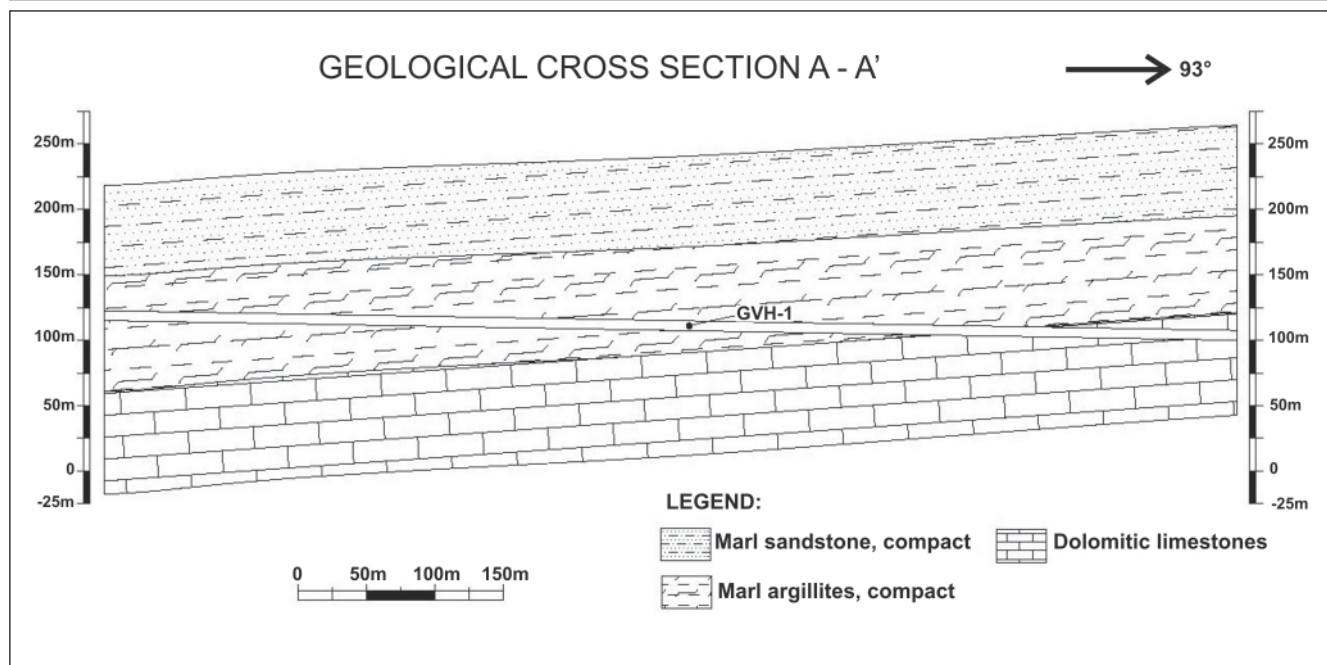


Figure 3 - Geological cross section longitudinal to drive GVH-1.

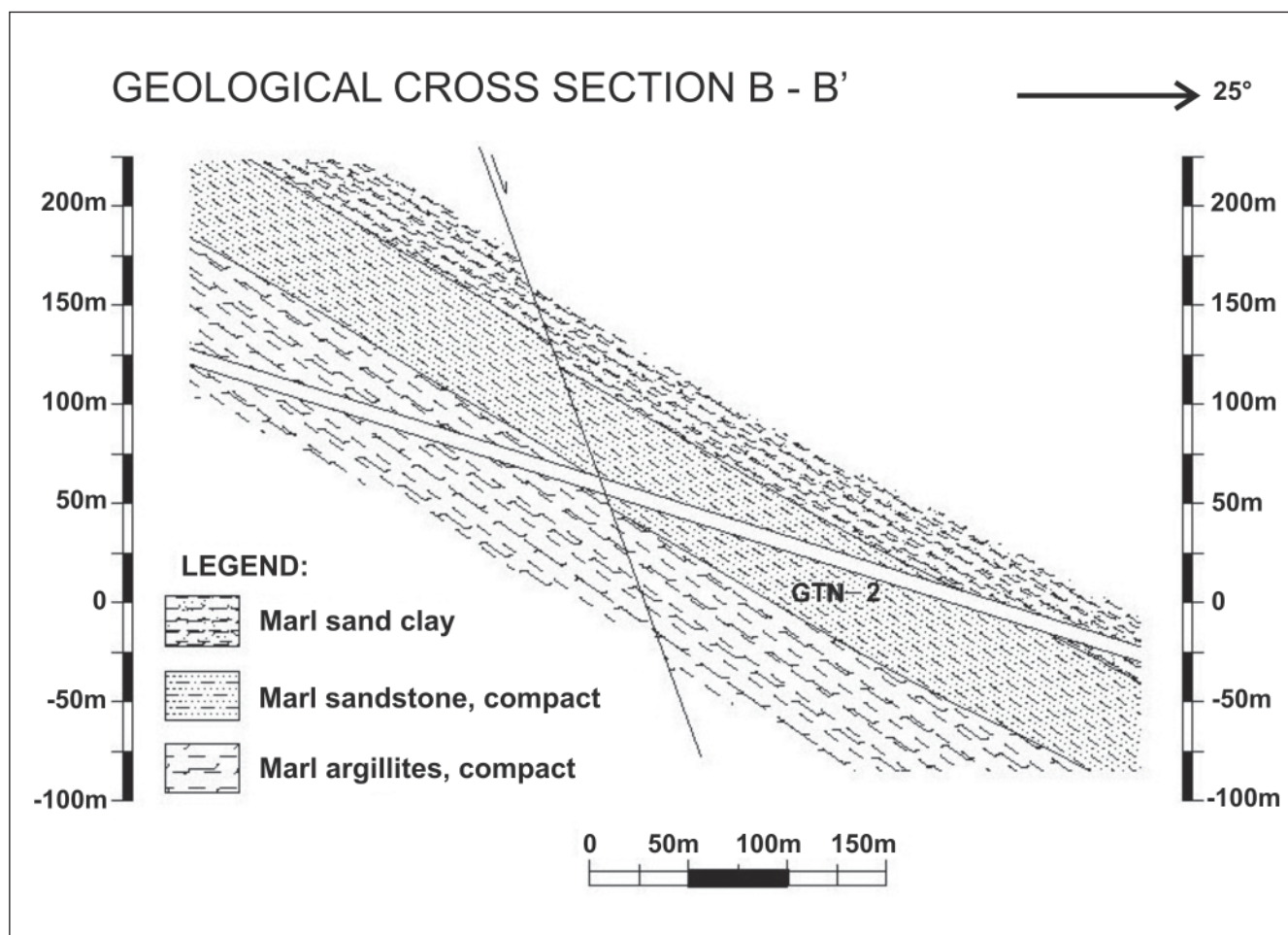


Figure 4 - Geological cross section longitudinal to drive GTN-2.

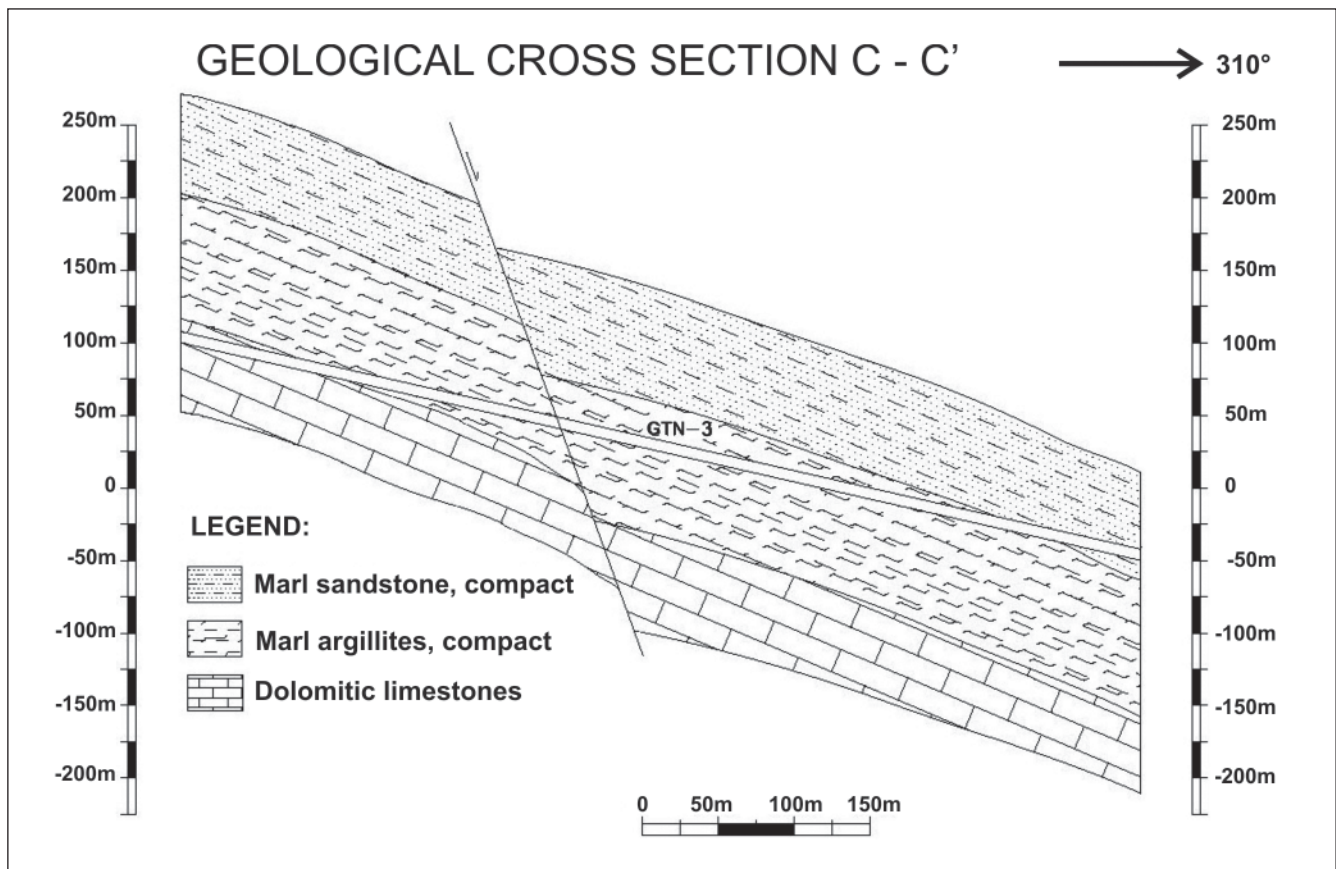


Figure 5 - Geological cross section longitudinal to drive GTN-3.

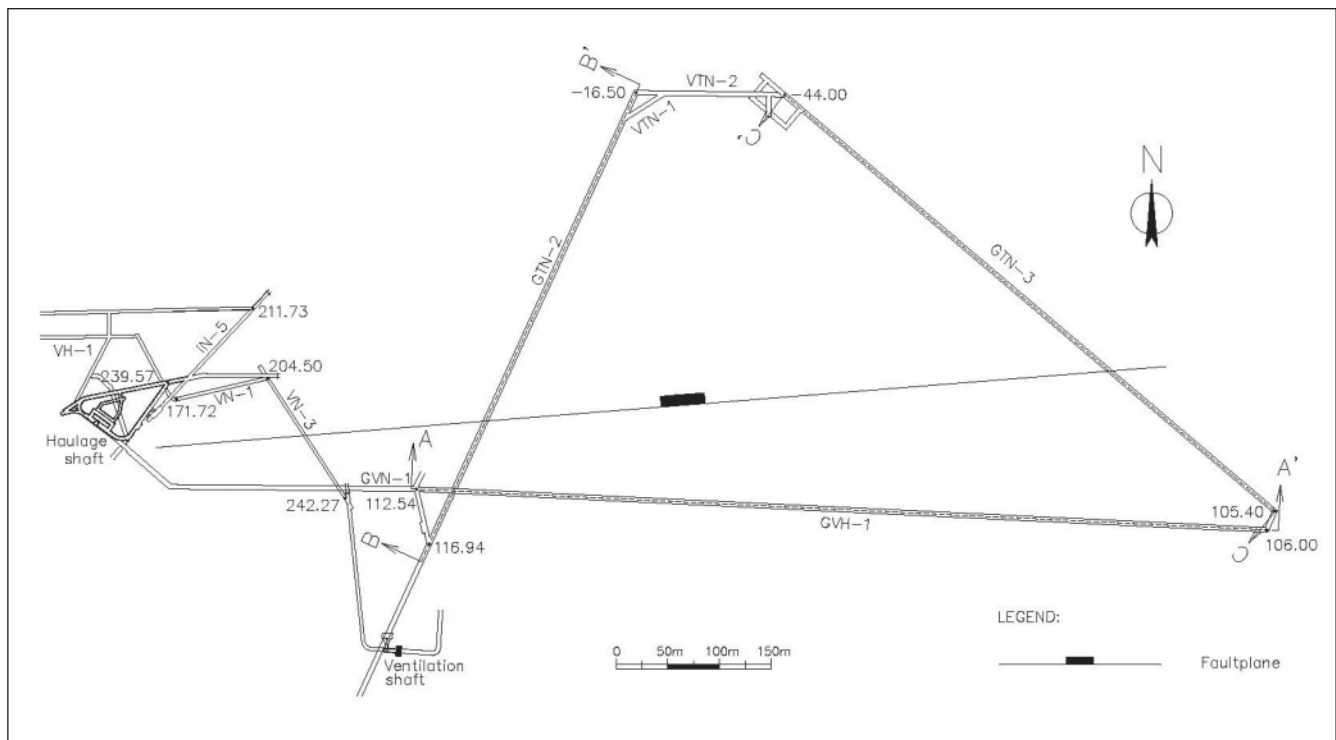


Figure 6 - General layout of the working drives of the Central field's -44m level.

Table 1 - Results of measurements of horizontal directions and lengths.

Horizontal directions						Horizontal lengths			
Station	Sight	°	'	"		from	to	[m]	
1	2	0	0	00.0	α_1	1	2	18.2560	d_1
	P ₁	214	22	49.3	α_2	1	P ₁	6.9189	d_2
	P ₂	215	31	41.5	α_3	1	P ₂	4.6474	d_3

Table 2 - Coefficients and free elements of the final residual equations.

s	i	n _{si}			d _{si} [m]	a _{si}	b _{si}	f _α ["]
1	2	60°	12'	13.4"	18.2566	9.8045	-5.6142	0
1	P ₁	274°	34'	57.7"	6.9213	-29.7061	-2.3811	-5.02
1	P ₂	275°	43'	50.6"	4.6468	-44.1665	-4.4323	-4.38
						A _{si}	B _{si}	f _d [mm]
1	2					-0.4969	-0.8678	+0.56
1	P ₁					-0.0799	+0.9968	+2.43
1	P ₂					-0.0999	+0.9950	-0.58

- Approximate coordinates of the points 1 and 2 in the haulage drive:

$$Y_1^\circ = 667.2730m \quad X_1^\circ = 812.2250m$$

$$Y_2^\circ = 683.1160m \quad X_2^\circ = 821.2970m$$

- Results of measurements of horizontal directions and lengths in the haulage drive (Table 1).
- Standard deviations to the measured values:

$$\sigma_\alpha = 5'' \quad \sigma_d = 0.5mm$$

Based on the parametric adjustment procedure, coefficients and free elements of the final residual equations are calculated according to equations (8) and (15) (Table 2).

Therefore according to the set of equations (17), the coefficient matrix of the residual equations will be:

$$A = \begin{bmatrix} +9.8045 & -5.6142 & +1 & -9.8045 & +5.6142 \\ -29.7061 & -2.3811 & +1 & 0 & 0 \\ -44.1665 & -4.4323 & +1 & 0 & 0 \\ -0.4969 & -0.8678 & 0 & +0.4969 & +0.8678 \\ -0.0799 & +0.9968 & 0 & 0 & 0 \\ -0.0999 & +0.9950 & 0 & 0 & 0 \end{bmatrix}$$

$$\text{Free element vector: } f^T = [0 \quad -5.02 \quad -4.38 \quad +0.56 \quad +2.43 \quad -0.58]$$

$$\text{As well as the weight matrix: } P_{dijag} = \begin{bmatrix} 1 & 1 & 1 & 100 & 100 & 100 \end{bmatrix}$$

By applying the corresponding matrix operations, an inverse coefficient matrix of standard equations is obtained:

$$N^{-1} = \begin{bmatrix} +0.0094 & +0.0001 & +0.3485 & +0.0362 & -0.0152 \\ +0.0001 & +0.0050 & +0.0223 & +0.0019 & +0.0040 \\ +0.3485 & +0.0223 & +13.4478 & +1.3814 & -0.5691 \\ +0.0362 & +0.0019 & +1.3814 & +0.1507 & -0.0580 \\ -0.0152 & +0.0040 & -0.5691 & -0.0580 & +0.0385 \end{bmatrix}$$

Where: $N = A^T \cdot P \cdot A$

As well as the free element vector:

$$n^T = (A^T \cdot P \cdot f)^T = [+301.2832 \quad +167.7458 \quad -9.4006 \quad +27.6232 \quad +48.2401]$$

Based on the coefficient matrix and free element vector, the increment vector is obtained:

$$x^T = -(N^{-1} \cdot n)^T = [+0.146\text{mm} \quad -0.915\text{mm} \quad +6.976'' \quad +0.406\text{mm} \quad -1.705\text{mm}]$$

The most probable values of the coordinates of unknown points in the haulage drive obtained by the parametric adjustment will be:

$$Y_1 = 667.2730\text{m} - 0.9\text{mm} = 667.2721\text{m} \quad X_1 = 812.2250\text{m} + 0.1\text{mm} = 812.2251\text{m}$$

$$Y_2 = 683.1160\text{m} - 1.7\text{mm} = 683.1143\text{m} \quad X_2 = 821.2970\text{m} + 0.4\text{mm} = 821.2974\text{m}$$

The transposed residual vector for the measurement results will be:

$$v^T = [0 \quad -0,21'' \quad +0,21'' \quad 0 \quad +1,50\text{mm} \quad -1,50\text{mm}]$$

And the most probable values of the measured values in the haulage drive will be in Table 3.

The standard deviations to the coordinates of the unknown points in the haulage drive are:

$$\sigma_{y1} = 1.50\text{mm} \quad \sigma_{x1} = 2.06\text{mm}$$

$$\sigma_{y2} = 4.17\text{mm} \quad \sigma_{x2} = 8.25\text{mm}$$

For the purposes of control, a conditional adjustment of the junction triangle was also carried out, with the same parameters ($P_1P_2 = 2.2773\text{m}$) and the following adjusted values:

- Angle between plumb lines $\gamma = 1^\circ 08' 52.3''$ (the difference between the value obtained by the parametric adjustment and the conditional one is $\Delta = |0.3''|$).

- Side distance between the plumb line P_1 and the point 1 in the haulage drive $d_2 = 6.9199\text{m}$ ($\Delta = |0.5\text{mm}|$).
- Side distance between the plumb line P_2 and the point 1 in the haulage drive $d_3 = 4.6464\text{m}$ ($\Delta = |0.4\text{mm}|$).

The coordinates of points 1 and 2 in the haulage drive are calculated in the draft of traverse, on the basis of conditionally adjusted measurements as follows:

$$Y_1 = 667.2716\text{m}$$

$$X_1 = 812.2250\text{m}$$

$$Y_2 = 683.1140\text{m}$$

$$X_2 = 821.2969\text{m}$$

And, as it was expected, these coordinates differ only slightly from the coordinates obtained by the parametric adjustment.

5. Conclusion

The parametric adjustment is a strict adjustment method based on the least-squares method. As such, the parametric adjustment, if well performed, will give the same results as any other adjustment based on the least-square method. In comparison with other strict adjustment methods, the parametric adjustment has several advantages of which the most important are: direct calculation of unknown coordinates and an indirect assessment of the accuracy of the measurements performed and the coordinate calculations.

There are a number of commercial geodetic softwares in the market which

Table 3 - The most probable values of measurements.

Horizontal directions						Horizontal lengths			
Station	Sight	°	'	''		from	to	[m]	
1	2	0	0	00.0	α_1'	1	2	18.2560	d_1'
	P_1	214	22	49.1	α_2'	1	P_1	6.9204	d_2'
	P_2	215	31	41.7	α_3'	1	P_2	4.6459	d_3'

are also applied in underground mines in performing different tasks. The fact is that all softwares will give the same final results, if they are based on adjustment according to the least-squares method. However, end users are not familiar with the algorithm according to which the software is realized, that is, the unknown is the applied adjustment method according to which calculations are made.

The procedure shown in the paper enables a simple, but efficient verification method for commercial softwares and their determining method, if the calculations were made according to the least-squares method and if the obtained results are the most probable values of unknown variables. The verification of the procedure was made by comparing results obtained by the conditional adjustment method, on the example of the haulage drive connection in the coal mine Soko.

Thus the experts can, in practice, organize a measurement program in a

simpler and better way; that is, they can achieve better results and a more efficient work, and thereby ensure lower operating costs for the company.

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Model for the selection of the optimal location of a thermal power unit according to the external coal conveyance criterion

Miloš Grujić¹, Ivica Ristović² and Miodrag Grujić³

Model výberu optimálneho umiestnenia tepelnej jednotky podľa vonkajších uhoľných kritérií prevozu

Aggravated working conditions in Serbian underground coal mines, and increasingly worse natural conditions (increased depths of deposits, expressed tectonics, large inflows of underground waters etc.) resulted in higher exploitation costs which are at the threshold of profitability. This inevitably leads to the conclusion that it is necessary to link mines to thermal power plants and facilities. The Soko and Lubnica mines can operate cost-effectively if they ground their production on the needs of a thermal power-heating plant (TETO) which would supply the towns of Bor and Zaječar with the power. This paper deals with finding an optimal location of a TETO using model for the optimal external coal conveyance from a mine to a thermal power unit.

Key words: model, coal conveyance, criterion

Introduction

Underground coal mines in Serbia pertain to the group of mines having small production and difficult natural conditions. In addition to that, long-standing delay in modernization of every stage of the exploitation has led to the obsolescence of the technology and to a very low utilization rate of a deposit. As a result of this, there are great losses in the production of every ton of coal.

A number of analyses, made for the needs of these mines, have shown that those can subsist only if they had the assured placement of coal in the market. Previously, the consumers of this coal were industrial and large-scale consumers, with a very small share in the production of the electric power. Since in a number of towns and regions, there is a need for the construction, of capacities for a centralized system of thermal energy supply, this means that several mines have an open possibility to solve, for a longer period of time, the issue of placing their coal in the market without big oscillations.

The aim of this paper is to point out to the possibility of placing the coal from two mines (Soko and Lubnica) for the needs of one thermal power-heating plant (TETO) which would supply with energy two towns in Eastern Serbia. The focus was put on making a model for the selection of the optimal location of a TETO according to the coal conveyance criterion with a view to supplying this facility.

Main assumptions of making the model for the selection of the most suitable location of a TETO

The development of Bor and Zaječar towns also requires a stable supply with all forms of needed energy. This includes the reliable supplying apartment houses and industrial facilities with thermal energy for heating, as a supplementary unburdening of the power energy producers (Electric Power Industry of Serbia – EPS) in the area of these towns. The existing facilities in the above towns cannot completely meet the requirements; since they cannot guarantee the capacities, they have large costs and depend on oscillations in energy supply.

On the other hand, the coal mines Lubnica and Soko jointly dispose of mining reserves which could ensure, from domestic resources, the secure and reliable supply with energy resources of a small-capacity, up to 80 MW, thermal power plant. This issue is not new, it was considered on many occasions, there was even created a joint venture of the town of Zaječar and the Czech company ENERGO-MORAVIA. A few

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steps were made to this end, but there was no big progress due to the fact that the mining reserves in the Lubnica mine were not correctly defined, although it was intended to be the main coal provider. In the meantime, the beforementioned Czech company bankrupted.

Bearing in mind the mutual interest both of coal mine and the local self-governments of towns Bor and Zaječar, it was necessary to reactivate this initiative with slightly changed conditions. We primarily mean the enlargement of the scope of users, by including the town of Bor, and finding a new location which would give a rational solution for the supply of both towns, but which would be optimal in respect of coal conveyance from the mines Soko and Lubnica.

In order to make it possible, it is necessary to make a study which would result in the optimal location of a thermal power-heating plant. The findings of the study would be based on a number of criteria where the most important are:

- Specific costs of coal conveyance,
- Costs of the transmission of the thermal energy from a TETO to consumers by thermal pipe systems,
- Amount of initial investments into a TETO,
- Environmental protection,
- Required investments into mines,
- Possibility of using the electric energy obtained in the process of the co-generation etc.

In making the study, the results obtained also in the process of the operation of the joint ventures Energo-Moravia and the town of Zaječar would be used. Also, the existing technical documentation of the PE Underground Exploitation of Mines and of the Soko and Lubnica mines would be utilized.

Bearing in mind the complexity of the operation and the existence of many influencing parameters, the model for solving this and related issues was developed at the Department for haulage at the Faculty of Mining and Geology. The model for the selection of the best location consists of several main blocks:

A. Determining needs, potential and coal reserves of a TETO

In this block it is envisaged to determine input parameters according which it is necessary to define the most suitable solutions for locating a thermal power unit based on the needs of the population and on the potential of the mines Soko and Lubnica. Therefore, it is necessary to define the following steps in this part of the model:

- determining the necessary power of a TETO,
- specified calorific power of fuel for the needs of a TETO,
- Mining reserves of the Soko Mine,
- Mining reserves of the Lubnica Mine,
- determining the share ratio of coal from certain mines in order to achieve the specified calorific power,
- Necessary variety of coal for the optimized operation of a TETO.

The most delicate issue in this part of the model is determining the real ratio between needs, wishes and potentials of a mine, i.e. of a supplier with power fuels.

B. Determining and analysis of possible locations and conveyance variants

This model block virtually consists of two units, for which it is necessary, in further development, to establish mutual relations. The first part refers to the determination of possible locations of a TETO, and possible variants of conveyance are analyzed in the second part. The most significant items of the B block are as follows:

- Locations of TETO which are suitable in respect of the distance from a power consumer,
- Locations of TETO which comply with the requirements of the environmental protection,
- Possible locations of TETO with suitable infrastructure,
- Possibilities of truck coal transportation,
- Variants of the combined coal conveyance,
- Possibilities of a hydraulic coal conveyance,
- Possibilities of coal conveyance from a mine to a TETO, with the involvement of third parties (transportation services).

Each of possible variants has a number of sub-variants, i.e. it has a number of possible solutions within one possibility. This especially applies to the possibilities of the transportation, where each of the 4 main variants has 3 sub-variants on the average.

C. Techno-economical analysis of possible variants

For the techno-economical analysis of previously defined possible locations of a thermal power-heating plant and of defined variants of coal conveyance from a mine to thermal power units, the following steps are required:

- Techno-economical analysis of each variant of truck transportation,
- Techno-economical analysis of possible variants of the combined transportation,
- Techno-economical analysis of the hydraulic coal conveyance,
- determining the average price of the third party transportation service,
- ranking according to minimal specific costs of coal conveyance.

The techno-economical analysis provides reliable information about technical possibilities and specific costs per unit of a product or a service. However, for a correct and final decision, it is also necessary to perform a multi-criteria analysis, which would include some criteria that are not stated through the techno-economical analysis.

D. Multi-criteria analysis for determining an optimal location of a TETO

For the purposes of the model for the selection of the most suitable location of a TETO, in this part the following issues are defined:

- determining the criteria for the analysis and their quantification,
- determining the Importance Coefficients for each criterion,
- applying the methods of the multi-criteria decision-making,
- Ranking variants according to the methods of the multi-criteria analysis.

The main issue emerged at the beginning of working on the multi-criteria analysis was to determine Importance Coefficients for each criterion. After analyzing mutual influences of all of the criteria, the following Importance Coefficients have been determined:

1. specific costs of coal conveyance..... 0.55
2. costs of thermal energy transmission from a TETO to consumers.. 0.15
3. environmental protection..... 0.10
4. required investments into mines..... 0.05
5. Amount of initial investments into the TETO..... 0.15

As multi-criteria decision-making methods, the PROMETHE method was selected as the main method, and matrix method as the control one. The Department for mine haulage at the Faculty of Mining and Geology in Belgrade has positive experiences in applying these methods.

Conclusion

The need for using all energy resources in Serbia and the quite unfavourable situation in regard to the heating of medium-size towns, have led to the idea that several regional thermal power units should be constructed. Thereat it would be necessary to direct them to use domestic coal as the power fuel. In order to make sure that this is economically, environmentally and anthropologically justifiable, it is necessary to determine the optimal location of a TETO, along with bearing in mind, in the first place, the issue of coal conveyance, as one of the most influencing parameters. In order to make such decision, it is necessary to apply a model which would include all parameters and criteria, whereby the appropriate importance is attached to each of them.

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В.4 Учешће у организационим и научним одборима конференција и часописа

Др Ивица Ристовић је технички уредник, члан уређивачког програмског одбора и члан научног одбора водећег часописа националног значаја Транспорт и логистика. Такође је члан научног одбора часописа националног значаја Подземни радови. Поред тога је:

- Председник организационог одбора, Уредник Зборника радова, и члан Научног одбора Међународног симпозијума Енергетско Рударство ЕР, РГФ, Београд.
- Потпредседник организационог одбора Међународне конференције Investigation, Production and Use of Steel Ropes, Conveyors and Hoisting Machines, ТУ Кошице, БЕРГ факултет, Кошице, Словачка.
- Потпредседник организационог одбора и члан научног одбора Интернационалног симпозијума о транспорту и извозу ИСТИ, РГФ, Београд.
- Потпредседник организационог одбора и члан Научног одбора Интернационалног симпозијума о Заштити животне средине у рударству МЕР, РГФ, Београд.
- Члан научног одбора Међународне конференције ECOS 2011, Нови Сад.
- Члан научног одбора Међународне конференције Sustainable development of energy water and environment systems, Дубровник.
- Члан научног одбора Међународног симпозијума Заштита животне средине у индустријским подручјима, Факултет техничких наука, Косовска Митровица.

Г. УЧЕШЋЕ И РУКОВОЂЕЊЕ ПРОЈЕКТИМА

Др Ивица Ристовић је активан учесник у већини научних и стручних пројеката и студија који се реализују на Катедри за транспорт у рударству и Рударском одсеку. Учествовао је у реализацији преко 40 научних и стручних пројеката, студија и елабората, од којих су најважнији они **пројекти** који су финансирани од стране Министарства за науку и технологију, као и три Међународна билатерална пројекта. Пројекти који су финансирани од стране Министарства за науку и технологију:

1. Фундаменталне науке: НП 08М07: Истраживање нових технологија и метода експлоатације, опреме и управљачких система у циљу рационалног искоришћења енергетских минералних сировина, Београд, 1995-2000.
2. Технолошки развој: ТР 0217: Унапређење технолошких процеса подземне експлоатације угља у новонасталим условима привређивања, Београд 2002-2003.
3. Технолошки развој: ТР 0247: Ревитализација и модернизација система роторни багер транспортер-одлагач на површинским коповима, Београд 2002-2003.
4. Технолошки развој: ТР, Подземна експлоатација малих лежишта минералних сировина, Београд 2002-2003.
5. ЕЕ 210189: Управљање процесом хомогенизације угља у циљу повећања искоришћења нискоквалитетних угљева и уштеде мазута у термоелектранама, Београд, 2004-2005.
6. ЕЕ 1018А: Повећање енергетске ефикасности континуалних транспортних система са траком у рудницима угља са подземном експлоатацијом рационализацијом и увођењем система аутоматског управљања, Београд 2005.
7. ТР 6641А Оптимизација система за транспорт ископине, превоз људи и допрему репроматеријала у подземним рудницима угља Србије, Београд, 2005-2007.
8. ТР 17021: Истраживање технологија транспорта угља из рудника кроз природне и урбане средине, Београд 2008-2010 (**Руководилац Пројекта**).
9. ТР 33025: Истраживање могућности примене АТ висеће подграде у рудницима у циљу повећања безбедности рада и ефикасности производње. Београд, 2011-2014.
10. ТР 33039: Унапређење технологије површинске експлоатације лигнита у циљу повећања енергетске ефикасности, сигурности и заштите на раду, Београд, 2011-2014.

Пројекти међународне билатералне сарадње:

1. Research of Environment-Friendly External Ore Conveyance, University of Belgrade, Faculty of Mining and Geology – TU Košice, BERG Faculty, 2004-2006.
2. Information Systems in Transport of Mineral Raw Materials, University of Belgrade, Faculty of Mining and Geology – TU Košice, BERG Faculty, 2006-2008.
3. Design of Logistics Model for Mining Enterprise with Application of the Principles of Transport and Reverse Logistics, University of Belgrade, Faculty of Mining and Geology – TU Košice, BERG Faculty, 2010-2011.

Д. ЧЛАНСТВА У УДРУЖЕЊИМА И ПРОФЕСИОНАЛНЕ АКТИВНОСТИ

Др Ивица Ристовић је:

- Председник Групације за енергетско рударство ПК Србије од 2007. године и данас
- Члан Групације за заштиту животне средине ПК Србије од 2007. године и данас
- Члан Групације за обновљиве изворе енергије и енергетску ефикасност ПК Србије од 2004 - 2006. године.
- Члан Српског рударског друштва.
- Члан УО Алумни удружења Рударско-геолошког факултета у Београду.

Поред тога др Ивица Ристовић је био члан савета Рударско-геолошког факултета Универзитета у Београду у периоду од 2007 – 2009. године, а данас се налази на месту заменика Шефа Рударског одсека Рударско-геолошког факултета.

ЗАКЉУЧАК И ПРЕДЛОГ КОМИСИЈЕ

На расписани конкурс за радно место ванредног професора за ужу научну област **Експлоатација чврстих минералних сировина и механика стена**, пријавила су се два (2) кандидата:

1. др Велимир Шћекић ванредни професор Факултета за Индустијски менаџмент у Крушевцу, Универзитета Унион, и
2. др Ивица Ристовић, доцент на Катедри за Транспорт у рудницама, Рударског одсека, Рударско-геолошког факултета, Универзитета у Београду.

За првог кандидата, др Велимира Шћекића Комисија сматра да не испуњава услове Конкурса, који су одређени Критеријумима за стицање звања наставника на Универзитету у Београду („Гласник Универзитета у Београду“ бр. 144/2008).

Детаљно анализирајући наставничку, научну и стручну активност др Ивице Ристовић, Комисија је констатовала да се ради о афирмисаном научном раднику, једном од водећих стручњака на пољу Транспорта у рударству код нас.

Комисија је размотрила поднету документацију и закључила да кандидат Др Ивица Ристовић има:

- **Докторат** из научне области рударство за коју се бира;
- **Укупно 147 објављених научних и стручних радова** укључујући магистратуру, докторат, монографије и поглавља у монографијама националног и међународног значаја који представљају допринос афирмацији и развоју транспорта у рударству и заштити животне средине при транспорту минералних сировина. Од овог броја **23** рада је публиковано у часописима националног значаја, **46** радова на националним скуповима, **56** радова на међународним конгресима и симпозијумима, и **10** радова у научним часописима међународног значаја.

- У периоду од избора у звање доцента објављених **7 радова у међународним часописима са СЦИ листе са ИФ**, 4 рада у међународним часописима верификовани посебном одлуком, 3 предавања по позиву са међународног скупа штампаних у целини, 15 радова на међународном скупу, 7 радова у водећим часописима националног значаја, 1 предавање по позиву са скупа националног значаја, 11 саопштења са скупа националног значаја штампаних у целини. Уредник је 3 зборника саопштења са међународног скупа.
- У периоду од избора у звање доцента публикована 2 поглавља у монографији – тематском зборнику водећег међународног значаја, 1 поглавље у монографији међународног значаја, објављену 1 монографију националног значаја као аутор и 2 монографије националног значаја као коаутор. Уредник је 1 научне монографије националног значаја. Аутор је мултимедијалног садржаја намењеног студентима (са рецензијом): Континуални транспортни системи у подземној експлоатацији минералних сировина.
- Активно је учествовао у реализацији 10 пројеката Министарства за науку и технолошки развој - 3 од избора у звање. Био је **руководилац** 1 пројекта. Учесник је 3 међународна пројекта - билатерална сарадња.
- Од избора у звање доцента др Ивица Ристовић је учествовао у реализацији 5 дипломских радова, од чега је у 4 дипломска рада био ментор, 3 магистарска рада од којих је један био ментор, 1 завршни рад на мастер студијама – ментор. Ментор је једне докторске дисертације која је у току, а 3 пута је био члан комисије за одбрану докторске дисертације.
- Од доласка на Факултет, друштвено је веома активан. Од избора у звање доцента био је члан савета Рударско – геолошког факултета, а тренутно је на функцији заменика Шефа Рударског одсека.
- Задужен је за одржавање предавања и вежби на 8 предмета на основним академским студијама, 2 предмета на дипломским академским студијама и 1 предмет на докторским студијама.
- Према резултатима студентског вредновања наставника, др Ивица Ристовић је добио одличну просечну оцену: **(4,76)** за школску 2007/2008, **(4,57)**, **(4,50)** и **(4,97)** за школску 2008/2009 и **(4,98)** за школску 2009/2010.

На основу напред изнетог као и на основу Критеријума за стицање звања наставника на Универзитету у Београду, комисија је закључила да кандидат др Ивица Ристовић у потпуности испуњава услове за избор у звање ванредног професора, и са задовољством предлаже Наставно-научном већу Рударско-геолошког факултета Универзитета у Београду, да се Др Ивица Ристовић, дипл. инж. руд. изабере у звање **ВАНРЕДНОГ ПРОФЕСОРА ЗА УЖУ НАУЧНУ ОБЛАСТ ЕКСПЛОАТАЦИЈА ЧВРСТИХ МИНЕРАЛНИХ СИРОВИНА И МЕХАНИКА СТЕНА**, на Рударско-геолошком факултету, Универзитета у Београду.

Београд, 01.07.2011. године

ЧЛАНОВИ КОМИСИЈЕ:

Др Милош Грујић, ред.проф., Рударско-геолошки факултет, Београд

Др Божо Колоња, ред.проф., Рударско-геолошки факултет, Београд

Др Благоје Недељковић, ред.проф., Факултет техничких наука, Косовска Митровица
