SENSIBILITY ANALYSIS OF THE SUBSIDENCE PARAMETERS AT THE VARIATION OF THE MAIN GEO-MINING FACTORS

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In this paper, there are presented the results of a complex analysis, with finite element method modelling, on the influence of the coal mining subsidence parameters at the variation of the following geo-mining factors: main geo-mechanical features; mining depth; coal seam dip; mining goaf sizes; horizontal stress; the presence of the near mining space.

Keywords: *coal seam, subsidence, horizontal displacement, finite element method, geo-mechanical characteristics, mining depth, horizontal stresses.*

Introduction

The underground mining of the coal deposits by roof rock caving leads to the massive stress and strain change and implicitly to the ground surface deformation, where a subsidence basin is formed. The main parameters of the subsidence basin are the subsidence and horizontal displacement [3], [5], [6], [10]. To analyse the behaviour manner of these parameters at the variation of certain geo-mining factors, the 2D finite element modelling [4], [7], [8], [9] was used, with the aid of the CESAR-LCPC software [12]. In this effect, was achieved the homogenous numerical models and in the centre of these was executed the mining voids that simulate the extracted volume of the coal seam with longwall faces. In these models there were taken into consideration two zones of the massive with different characteristics, specifically for the rocks of the Jiu Valley coal basin [1], [11]: the first zone involves the surrounding rocks of the roof and floor of the coal seam and the second zone is attributed to the coal seam.

The rock characteristics, considered as homogenous and isotropic, taking into calculus the elasto – plastically without hardening behaviour hypothesis, are the following: apparent density; Young modulus of elasticity, *E*; Poisson ratio, ν; compressive strength, σ_c; tensile strength, σ_t; cohesion , *C*; internal friction angle, φ (Tab. 1) [1], [11].

Table 1 *Geo-mechanical characteristics values of the rocks of the two distinct areas of finite elements models*

Rock characteristic	Symbol	UM	Rocks	Coal
Apparent density	ρ_a	kg/m^3	2663	1450
Young modulus of elasticity	E	kN/m^2	5 035 000	1 035 000
Poisson ratio	ν	-	0,19	0,13
Cohesion	C	kN/m^2	6 130	1 300
Internal friction angle	φ	^{o}	55	50

Sensibility analysis of the physical and mechanical characteristics

Apparent density influence

In view to study the influence level of the apparent density of the rocks on the behaviour of finite element models, from the point of view of the main parameters of the subsidence, the average value of the rocks density will be multiplied by a coefficient *K* (*K*=1; 1.3; 1.5; 1.7; 2) [7], [9], keeping the other parameters constant (at the value presented in the table 1). It's mentioned that the same sensibility analysis could be achieved taken as parameter the apparent specific weight.

By consequence of the calculus made on these models it was found that the subsidence and horizontal displacement increase linearly at the same time with the apparent density increase (Fig.1), which demonstrates the pronounced sensitivity of the model at the rock density variation (and implicitly of the apparent specific weight) [2]:

$$W_{\max} = 0.0585 \cdot \rho - 9.5178,\ R^2 = 0.9999 \quad (1)$$

$$U_{\max} = 0.0211 \cdot \rho - 4.1921,\ R^2 = 0.9998 \quad (2)$$

$$U_{\min} = -0.0166 \cdot \rho + 0.3737,\ R^2 = 0.9999 \quad (3)$$

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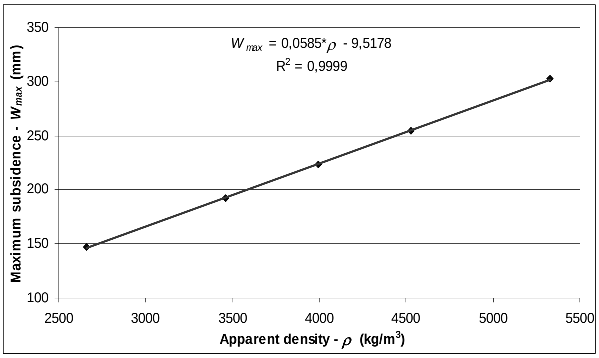

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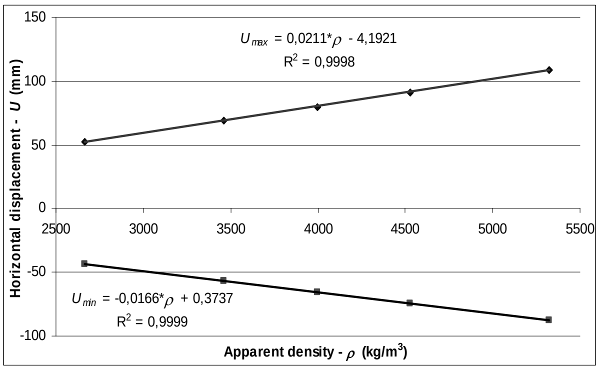

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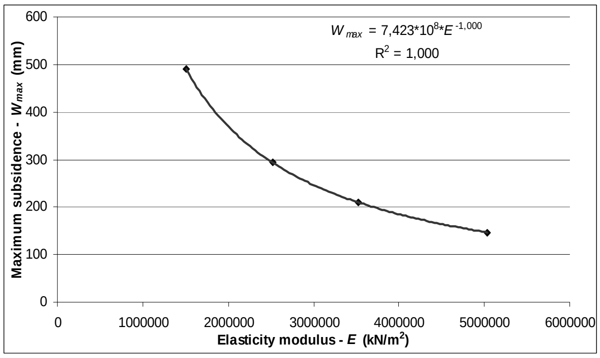
Fig.1. *Apparent density influence on the:*
a) maximum subsidence;
b) maximum / minimum horizontal displacement



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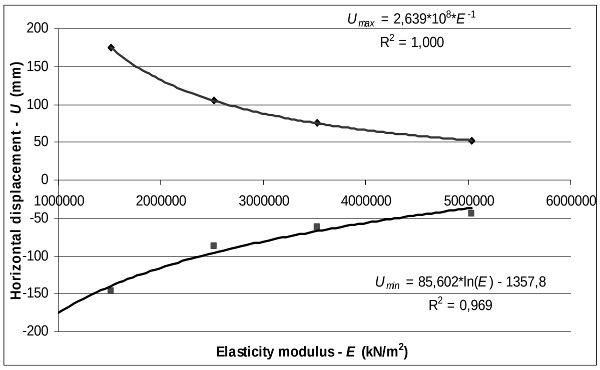

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Fig.2. *Elasticity modulus influence on the:*
a) maximum subsidence;
b) max / min horizontal displacement

Elasticity modulus influence

The study of the rocks elasticity modulus influence [1], [11] on the development of the main subsidence parameters was made by reducing the value of this main parameter that characterises the elastically behaviour of rocks with a coefficient *K* (*K*=1; 0.7; 0.5; 0.3) [7], [9], keeping the other parameters unchanged, in conformity with the values from Table 1.

In analysis of the obtained results from the finite element models it was concluded that the subsidence and horizontal displacement increases significantly with the elasticity modulus decrease (Fig.2), which shows a very large impact of the elasticity modulus on the model behaviour. The variation of the main subsidence parameters depending on the rocks elasticity modulus is shown in the following relations [2]:

$$W_{\max} = 7.423 \cdot 10^8 \cdot \frac{1}{E},\ R^2=1.0 \qquad (4)$$

$$U_{\max} = 2.639 \cdot 10^8 \cdot \frac{1}{E},\ R^2=1.0 \qquad (5)$$

$$U_{\min} = 85.602 \cdot \ln E - 1357.8,\ R^2=0.969 \qquad (6)$$

Poisson ratio influence

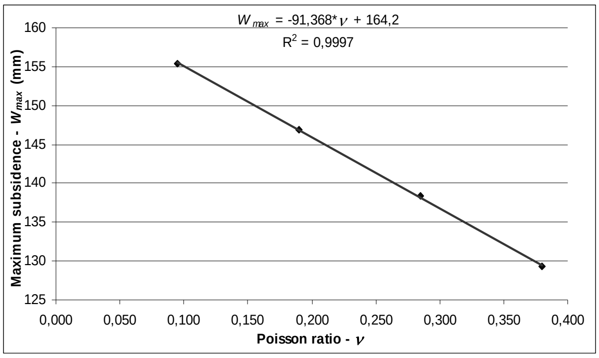
The model behaviour at the Poisson ration variation [1], [11] was obtained multiplying this parameter by a coefficient *K* (*K*=0.5; 1; 1.5; 2) and keeping the other parameters constant at the values shown in Table 1.

After analysis, it was concluded that the subsidence parameters (subsidence and displacement) have very little sensitivity at the Poisson ratio increase (Fig.3) [2]:

$$W_{\max} = -91.368 \cdot \nu + 164{,}2,\quad R^2=0.999 \qquad (7)$$

$$U_{\max} = -15.053 \cdot \nu + 55{,}15,\quad R^2=0.969 \qquad (8)$$

$$U_{\min} = 48.316 \cdot \nu - 52{,}6,\quad R^2=0.989 \qquad (9)$$



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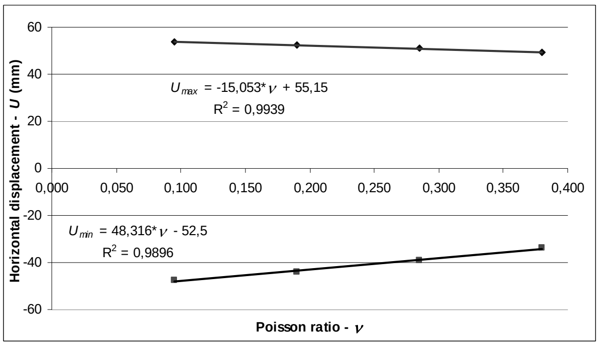

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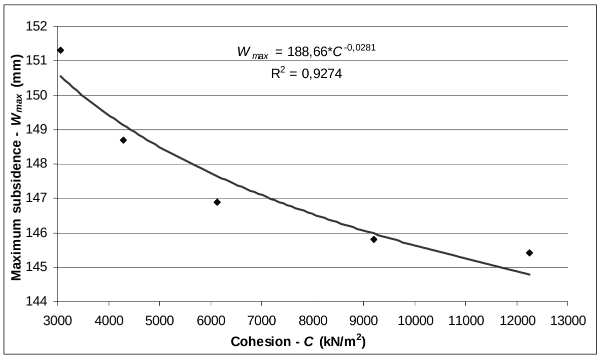
Fig.3. *Poisson ratio influence on the:*
a) maximum subsidence;
b) maximum / minimum horizontal displacement



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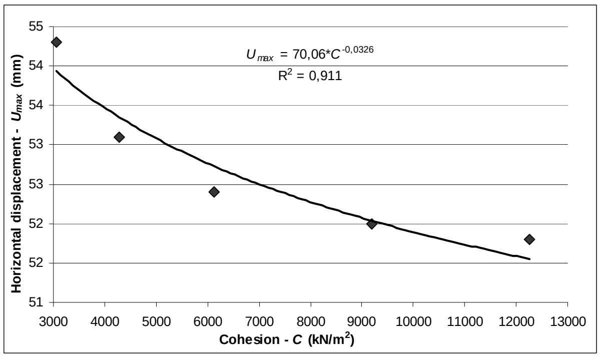

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Fig.4. *Poisson ratio influence on the:*
a) maximum subsidence;
b) maximum horizontal displacement

Cohesion influence

To analyse the models subsidence behaviour in function of the rocks cohesion [1], [11] the cohesion will be multiplied by a coefficient K (K=0.5; 1; 1.5; 2) and keeping the other parameters constant.

After calculus on these finite element models, results that the subsidence and horizontal displacement decreases slowly with the cohesion increase (Fig.4). Therefore, it could be concluded that the variations of the cohesion influences the model very little, in conformity with the following correlations [2]:

$$W_{\max} = 188.66 \cdot \frac{1}{C^{0.0281}}, R^2=0.927 \qquad (10)$$

$$U_{\max} = 70.06 \cdot \frac{1}{C^{0.0328}}, R^2=0.911 \qquad (11)$$

Influence of the internal friction angle

The study of the behaviour of the subsidence and horizontal displacement of the ground surface in function of the variation of the rocks internal friction angle [1], [11] was made by successively reducing the internal friction angle by a coefficient K (K=1; 0.7; 0.5; 0.3), keeping the other parameters constant (Table 1).

After analysis, it was observed that the subsidence parameters decrease very little with increase of the internal friction angle (Fig.5), following the laws [2]:

$$W_{\max} = 209.25 \cdot \frac{1}{\varphi^{0.0927}}, R^2=0.8664 \qquad (12)$$

$$U_{\max} = 73.749 \cdot \frac{1}{\varphi^{0.0897}}, R^2=0.8612 \qquad (13)$$

This leads to the conclusion that variations of the internal friction angle influence the main subsidence parameters in little measure.

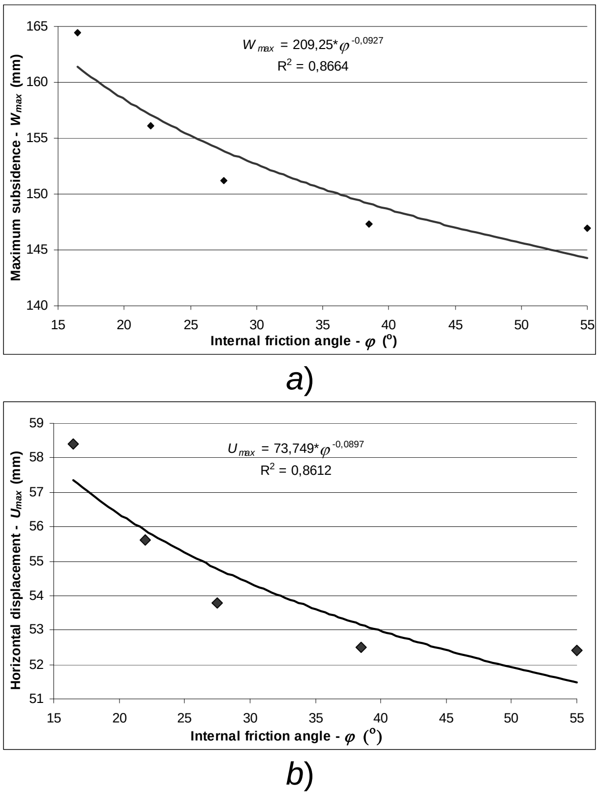


Fig.5. *Internal friction angle influence on the: a) maximum subsidence; b) maximum horizontal displacement*

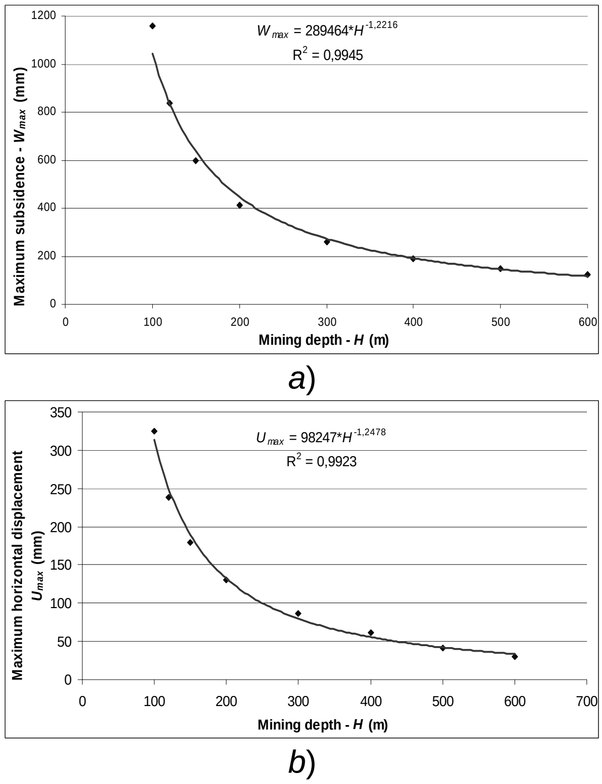


Fig. 6. *Mining depth influence on the: a) maximum subsidence; b) maximum horizontal displacement*

Sensibility analysis at the mining depth variation

The behaviour of the model at the mining depth variation (or the thickness of the roof rocks strata) was studied using several finite element models, for which the mining goaf was situated successively at various depths (*H*=100; 120; 150; 200; 300; 500; 600m).

In this case two massive zones with different characteristics were taken into consideration: first zone involves the surrounding rocks of the mined coal seam and the second zone is specific of the coal seam.

The rocks' characteristics of these two zones, considered homogenous and isotropic, in the Mohr – Coulomb elasto-plastic behaviour are presented in Table 1.

The models results show that the subsidence and the displacement very much increase with the mining depth decrease, especially at the depth less then *H*=200m (Fig.6) [2]:

$$W_{\max} = 289464 \cdot \frac{1}{H^{1.2216}}, \quad R^2 = 0.9945 \quad (14)$$

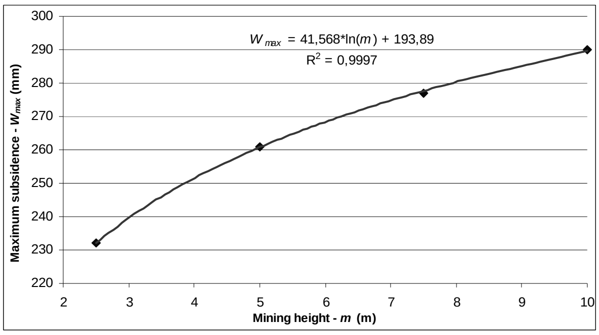
$$U_{\max} = 98247 \cdot \frac{1}{H^{1.2478}}, \quad R^2 = 0.9923 \quad (15)$$

The influence of the mining depth is explained by the increase of the vertical stresses (vertical and horizontal) developed in the rock massive with the depth increase, being directly proportional.

Sensibility analysis at the mining height variation

At this point, it was made an analysis of the behaviour of the finite element models at the mining height variation (or coal seam thickness). In this end, there were made several calculus variants where the coal seam was mined in the inclined slices with a height equal to 2.5m; the successive cases of the modelling being for 1 slice, 2, 3 and 4 simultaneous mining slices (respectively, for a mining height of: 2.5m; 5.0m; 7.5m and 10.0m).

From the calculus on these models, it was observed that the subsidence and the displacement increase logarithmically with the increase of the slices number or with increase of the mining height (Fig.7). This demonstrates the great influence of the mining height on the main parameters of the subsidence basin [2]:



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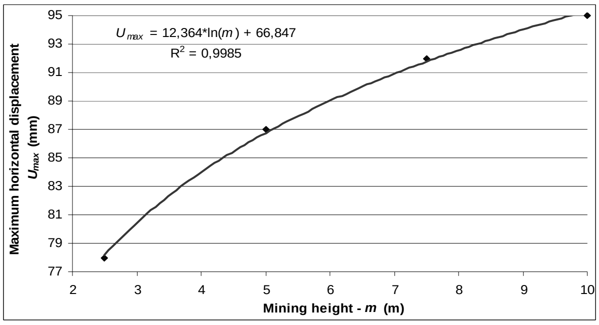

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Fig. 7. *Mining height influence on the:*
a) maximum subsidence;
b) maximum horizontal displacement

$$W_{\max} = 41.568 \cdot \ln m + 193.89 \text{ ,R}^2\text{=0.9997} \quad (16)$$

$$U_{\max} = 12.364 \cdot \ln m + 66.847 \text{ ,R}^2\text{=0.9985} \quad (17)$$

Sensibility analysis at the coal seam dip variation

The behaviour manner of the models (from the point of view of subsidence and horizontal displacement) in function of the dip coal seam variation was analysed in the conditions of the angles of : α = 0°; 5°; 10°; 15°; 20°; 25°; 30°; resulting 7 new models with different geometry.

After the analysis of the finite element models results, it could be observed that the maximum subsidence decreases with coal seam dip increase (Fig.8) and the subsidence basin is increasingly asymmetrical (Fig.9).

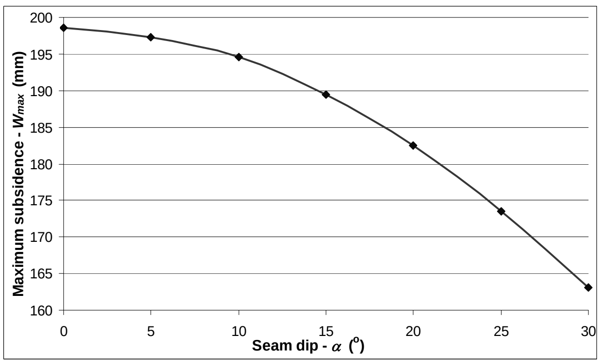


Fig. 8. *Coal seam dip influence on the maximum subsidence*

The representation of the subsidence basins in according with the coal seam dip is made in Figure 9 and the horizontal displacement curves in Figure 10.

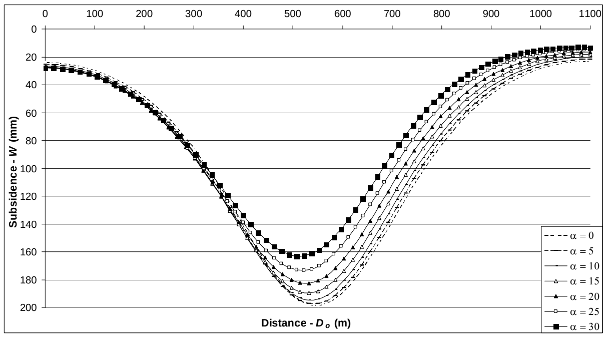


Fig. 9. *Subsidence basins in function of the coal seam dip variation*

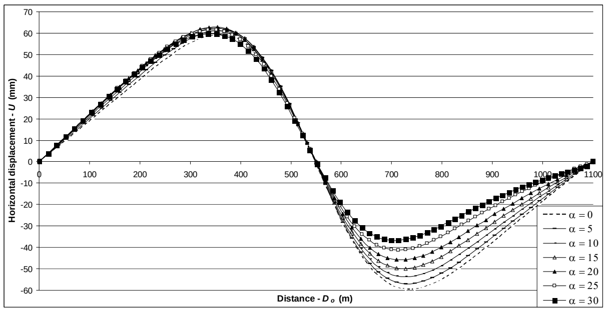


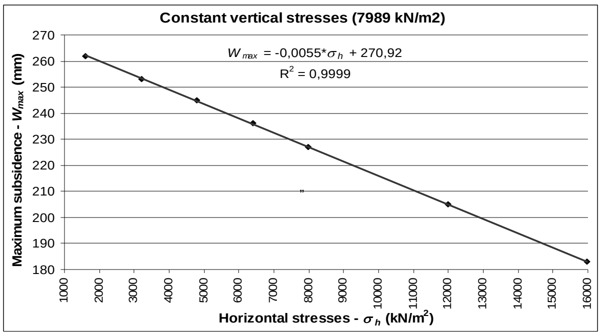
Fig. 10. *Horizontal displacements in function of the coal seam dip variation*

Sensibility analysis at the horizontal stresses variation

The sensibility analysis of the models at the horizontal stresses was made proceeding at successive calculus, on several models, with variable geostatic loadings, taking into consideration two regions with different characteristics (Table 1).

To analyse the model behaviour at the horizontal stresses (horizontal thrust) variation, $\sigma_h = \frac{\nu}{1-\nu} \cdot \sigma_v = k_{ox} \cdot \sigma_v$, developed in rock massive, the vertical stresses were considered constant and equal to $\sigma_v = \gamma \cdot H = 7989$ KN/m² and the parameter K_{ox} (the horizontal thrust coefficient) having different values (K_{ox} = 0.2; 0.4; 0.6; 0.8; 1; 1.5; 2). Thus results 7 different variants of the loadings of the finite element models.

After calculus, it was observed that the maximum subsidence and the horizontal displacement reduce linearly with increase of the horizontal stresses (Fig.11). It is worth mentioning that, in these conditions, the subsidence basin is larger for the important stresses (Fig.12).



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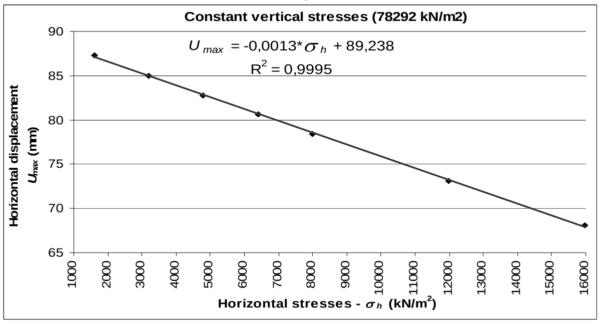

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Fig. 11. *Horizontal stresses influence on the: a) maximum subsidence; b) maximum horizontal displacement*

By consequence, the variation of these parameters is done by the following relations [2]:

$$W_{\max} = -0{,}0055 \cdot \sigma_h + 270{,}92 \text{ ,R}^2\text{=0,9999} \quad (18)$$

$$U_{\max} = -0{,}0013 \cdot \sigma_h + 89{,}238 \text{ ,R}^2\text{=0,9995} \quad (19)$$

The subsidence basins, related to the horizontal stresses with the previous values, are represented graphically in Figure 12, and the horizontal displacements in Figure 13.

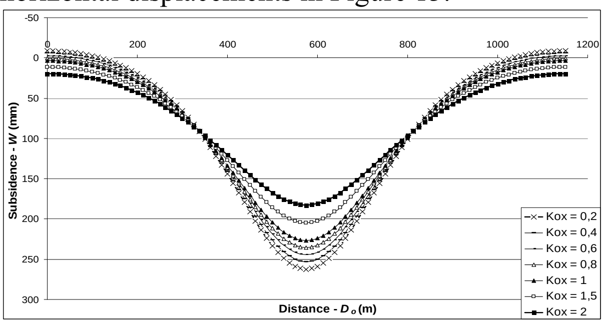

Fig. 12. *Representation of the subsidence basins in the case of the horizontal stresses variation*

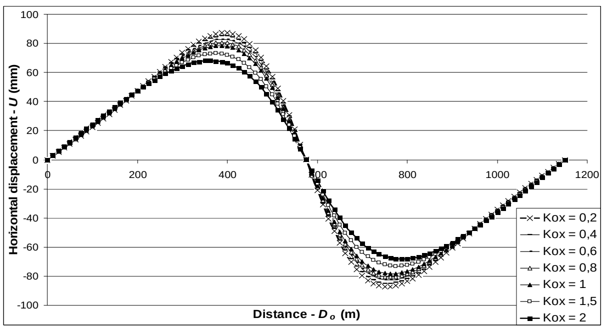

Fig. 13. *Representation of the horizontal displacements in the case of the horizontal stresses variation*

Ground surface deformation in the case of the underground mining of the two near coal seams

The influence of the two near coal seams on the ground surface stability was made by a general model, which: the coal seams are horizontal and symmetrically superposed, the goafs having the same sizes and the distance between them is of 100m (Fig.14).

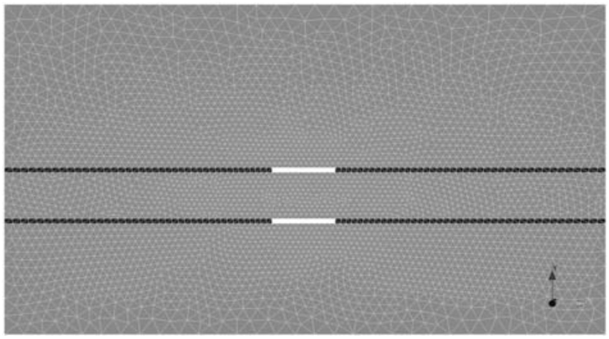

Fig. 14. *Finite element model in the case of two near coal seam*

For this end three numerical models of calculus were generated: a model with these two coal seams in mining stage and other two models with every coal seam in independent mining stage.

The results of the calculus were synthesized in the Figures 15 and 16. In Figure 15 the subsidence is shown for these three computation cases and in the Figure 16 the horizontal displacement.

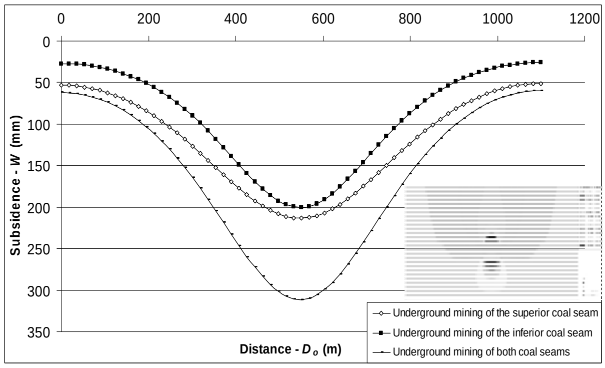

Fig. 15. *Subsidence basins representation in the case of two near coal seams mining*

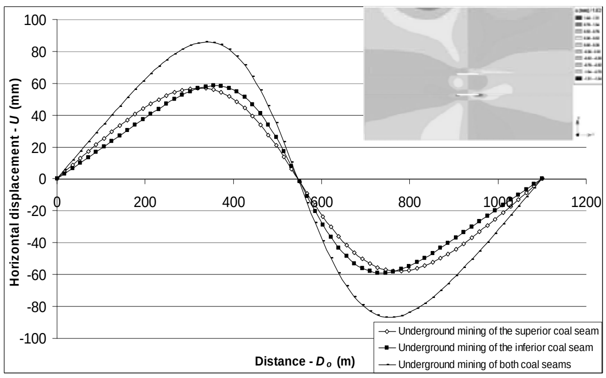

Fig. 16. *Horizontal displacement representation in the case of two near coal seams mining*

Analysing the variation of these two subsidence parameters it is obvious that the simultaneous mining of two coal seams has a more pronounced influence on the ground surface deformation; and the mining of the coal seam closer to the surface has a more important impact on the deformation parameters (subsidence and displacement) than the other coal seam situated at depth.

We note that the presented situation is a general one, very simplified; in reality, the displacement and the ground surface deformation, in the case of two or more near coal seams depend on several factors such as: the goaf sizes, coal seams dip, mining method, roof control procedure, distance between coal seams, position of the mined space, etc.

Conclusions

In view to analyse the sensibility of the main parameters of the subsidence basins (subsidence and horizontal displacement) at the variation of the geo-mining factors several 2D finite element models were made, in elasto-plasticity behaviour hypothesis, arriving at the following conclusions:

1) the apparent density or specific weight, by their contribution at the stress and strain state development, explain the pronounced sensibility of the subsidence and displacement at the variation of this parameter;

2) the subsidence and the displacement increase significantly with the elasticity modulus decrease;

3) the subsidence parameters are much less sensitive to the variation of the Poisson rate, cohesion and internal frictional angle;

4) the subsidence and displacement very much increase with the mining depth decrease, especially for the mining depth under 200m;

5) the subsidence and displacement increase logarithmically with the increase of the number of mined slices or mining height;

6) the maximum subsidence decreases with coal seam dip increase and the subsidence basin is increasingly asymmetrically;

7) the maximum subsidence and the horizontal displacement reduces linearly with increase of the horizontal stresses; in these conditions, the subsidence basin is larger for the important stresses;

8) the simultaneous mining of two coal seams has a more pronounced influence on the ground surface deformation; and the mining of the coal seam closer to the surface has a more important impact on the deformation parameters than the other coal seam situated at depth.

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