STABILITY BUILDINGS ANALYSIS IN THE JIU VALLEY TOP COAL CAVING MINING CONDITIONS, USING THE 3D FINITE ELEMENT MODELING

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Abstract
The effects of top coal caving mining of thick coal seams from the Jiu Valley are important ground deformations that are transmitted to surface construction. This paper presents the summary results obtained from finite element modelling of the underground mining's influence on a three levels building.
Key words: coal, mining, top coal caving, subsidence, horizontal displacement, stress

1. Description of finite element models

The research purpose is to study the behaviour of the buildings located on the ground surface of the Jiu Valley coal deposits, following the underground mining of the thick and low inclined coal seams, when top coal caving mining method is used. To achieve the goal mentioned a 3D modeling was used with the aid of the finite element software CESAR-LCPC, version 4 and the processor CLEO3D.

The modeling of the coal deposit mined, considered to be continuous, homogeneous and isotropic, has been carried out for the conditions of a thick and horizontally coal seam, with the average thickness of 9 m, situated at a depth of about H = 300 m, measured from the surface - the most common depth of the thick coal seam no. 3, with a low inclined areas of the Jiu Valley (example: Paroşeni and Livezeni mining fields). As a result from the finite element modeling, following sensitivity analysis of the various parameters used in the works (Marian, 2011, 2012; Onica & Marian, 2012, 2016; Marian & Onica, 2012; Ştefan, 2015), the coal seams inclination up to 18-20^o has not a major influence on the ground surface subsidence areas; in this respect, to represent a horizontally coal deposit was preferred in order to simplify the models construction with the "extrusion" tool aid.

For obtaining significant results, the coal seam no.3, with 9m of thickness (fig.1 and 2), was simulated to be in the final stage of the mining panel, with a total length of X_{ca} = 400m, and with a longwall length of l_{ab} = 150m.

Although the modelling hypothesis assumption it has been considered, in a simplified manner, that the surrounding rocks and coal are continuous, homogeneous and isotropic, however the mining method and technology with longwall face has been considered with top coal caving roof control (fig.3).

Regarding the three levels building, with its projection sizes in the horizontal plane of 20m, following the x axis and 10m, following the y axis, it was arranged on the vertical line of the mined panel centre. The levels, with height of 2,7m, were separated from each other by reinforced concrete ceilings, so as to result a building with three levels, to the total height of 8,1m.

Each level has been designed, on the long sides, with 4 windows, with dimensions of 1.2 m x 2 m, and on the short sides, with a single window, with size of 1m x 1,2 m (fig.1).

As can be seen in fig. 2, in 12 models were simulated 12 phases/panel mining sequences, from the starting gallery of the point A to the off point B or face equipment disassembly working, respectively for X_{ca} = 50m, 100m, 140m, 170m, 190m, 200m, 210m, 230m, 260m, 300m, 350m and 400m.

Because of the model symmetry after the $z0x$ vertical plane, following the direction of coal face advancement, in view to reduce the model sizes and implicitly to decrease the computation time, a symmetrical model was adopted by using that cutting plane (fig.1). Finally, a basis model has resulted, with the sizes of X = 2 500 m, Y = 500 m and Z = 409 m.

Regarding the rock massive representation, it was obtained from a plan meshing finite triangular elements model and by their sequential "extrusion" following the "z" axis, resulting volume finite elements with triangular prism shape, with the height disposed after that axis (Onica, 2016).

Because of the large volume of the rock massif models, of $511.25 \cdot 10^6$ m^3, requiring significant computing resources, to represent the building finite element model, respectively to generate the building walls and ceilings, we used also the "extrusion" tool of the CLEO3D processor, but this time applied to a linear finite element, to design the

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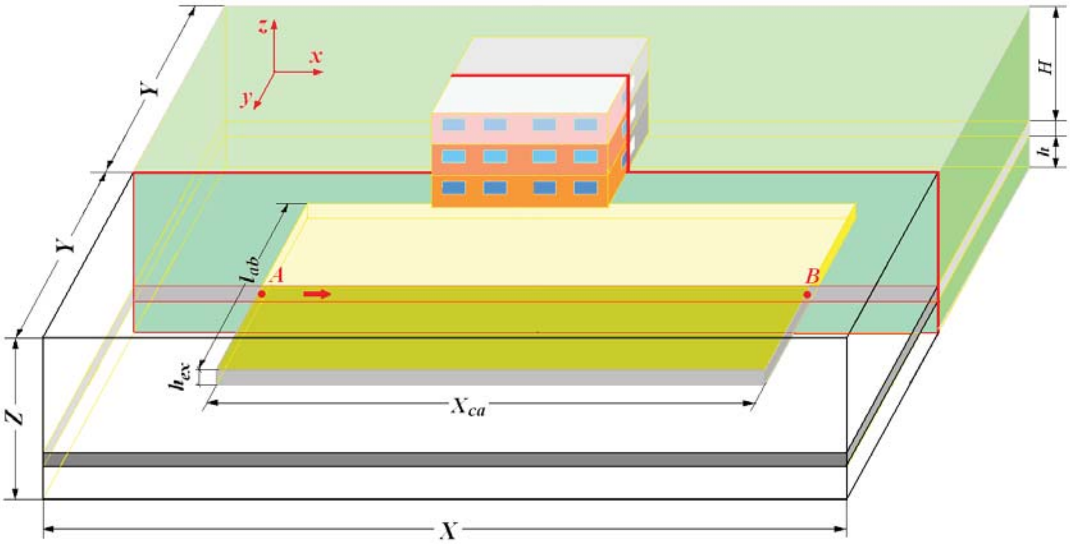

Fig.1. **Schematic representation of the 3D symmetrical finite element model, for analysis of the coal seam mining influence on a three levels building**

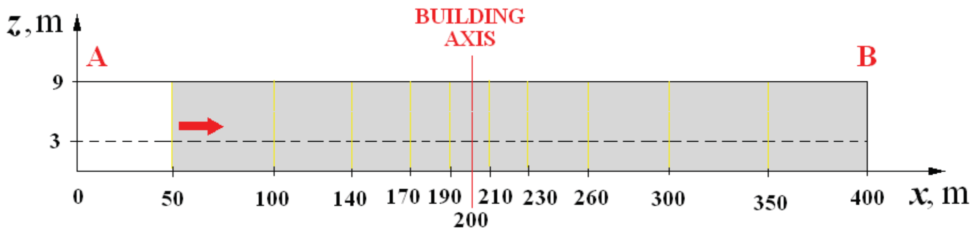

Fig.2. **Top coal caving longwall mining of a thick and gentle inclined coal seam**

"shell" type surface finite elements, with thickness of 0.3m.

The construction of the basic finite element model (which were derived from, the 12 individual models), was based on the following constructive characteristics: 23 712 nodes, 540 surface elements and 40 843 volume elements.

To implement the boundary conditions of the model, the following restrictions was imposed: for the lower limit, the movement along the *z* axis was blocked, and for the lateral limits, the movements regarding the *x* and *y* axis - maintaining the free movement for the other directions and for the ground surface (Onica, 2001).

Regarding constitutive materials laws used in the models, considering the very large sizes of the models, to reduce the computation time, an elastic behaviour hypothesis was chosen for both, the massive rocks and reinforced concrete of the building. This choice was determined by the fact that, in the case of similar models made by Marian (2011) and Ştefan (2015), using for the rock massive both laws of behaviour, elastic and elasto–plastic, the difference between results was non-significant. Therefore, in these models, for the massive rocks, the following characteristics have been adopted (Hirian, 1981; Todorescu, 1984): average apparent density $\rho_r = 2\,663$ kg /m^3, elasticity modulus $E_r = 1.511 \cdot 10^6$ kN /m^2 and Poisson's ratio $\nu_r = 0.19$; and for concrete, the following properties (Ştefanescu - Goangă, 1983; Teoreanu et al, 1982): apparent specific density $\rho_b = 2\,500$ kg/m^3, elasticity modulus $E_b = 30 \cdot 10^6$ kN/m^2, Poisson's ratio $\nu_b = 0.2$, cohesion C_b = 2 200 kN /m^2, angle of internal friction $\varphi_b = 55^o$, compressive strength $R_{c,b}$ = 16 000 kN /m^2 and tensile strength $R_{t,b}$ = 1 200 kN /m^2.

In the computations, the model charging "phases" option was used, with MCNL module of the CESAR solver. The initial phase of model charging was geostatic, with the average vertical stress of $\sigma_z = \gamma_r \cdot H$ = 8MN /m^2 and horizontal stress of $\sigma_x = \sigma_y = k_{ox} \cdot \sigma_z = k_{oy} \cdot \sigma_z$ = 2.64MN /m^2; the building was loaded by gravity, with the specific weight of the concrete..

2. Analysis of the ground surface deformations resulted from the top coal seam underground mining

From the beginning it could be said that the computations show the presence of the building in the finite element models has no influence on the ground surface deformation parameters.

The basic finite element model contains a coal seam with a thickness of 9 m, which is mined with a longwal face, with 150 m of length, by top coal caving mining technology. The coal face has a height of 3m and the top coal, 6m. Analysis of the ground surface deformation is made in 12 sequences of the panel mining. The top coal and roof rocks deformation under the stresses action, developed around the longwall face, is shown in the fig.3.

In the case of finite element modeling of the top coal caving longwall mining, schematized in the fig. 2, the maximum *horizontal displacement*, in the point where the mined panel has a length of X_{ca} = 50 m (longwall face is located at the 150 m, measured from the building axis), is of $\pm$ 8 mm, and it continued their development until the entire panel extraction, where it reaches the range of 136 mm $\div$ -136 mm, for the X_{ca} = 400m (fig. 4).

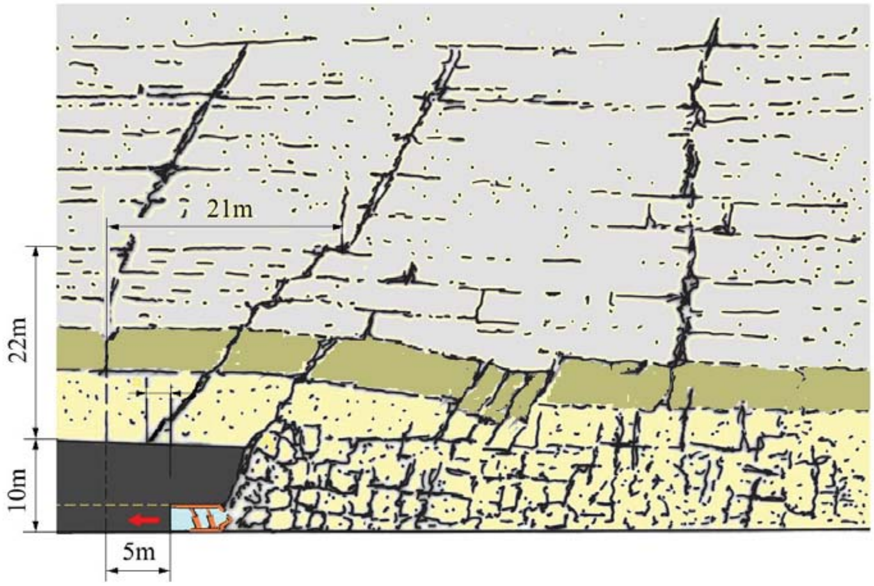

Fig.3. **Development of the roof rocks movement phenomenon, in the case of the top coal caving longwall mining (Qingkang et.al., 1988)**

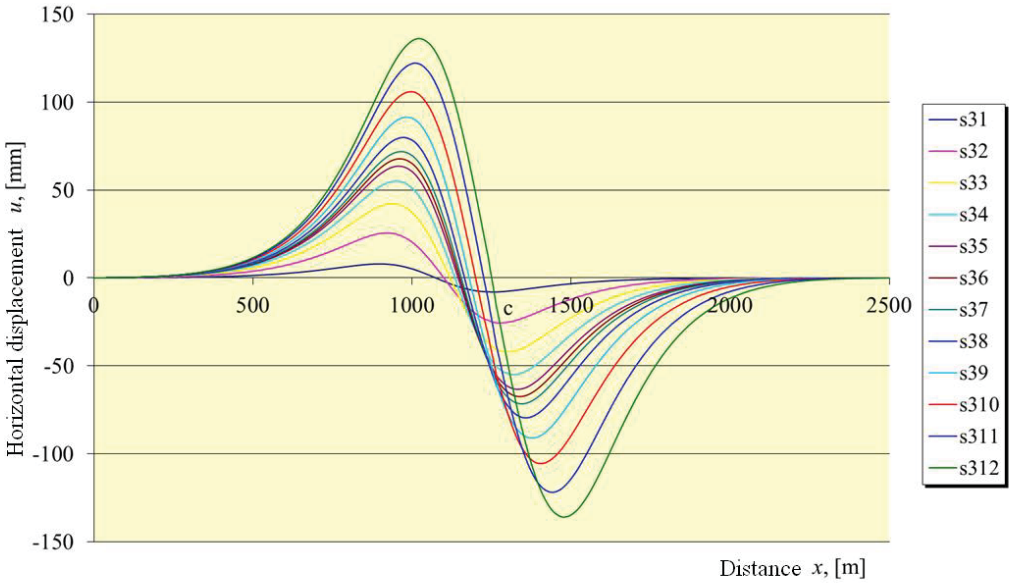

Fig. 4. **Evolution of horizontal displacement, in the case of the top coal caving longwall mining**
sij: i -number of building levels (i = 3); j - mining sequence (j = 1,2, .., 12)

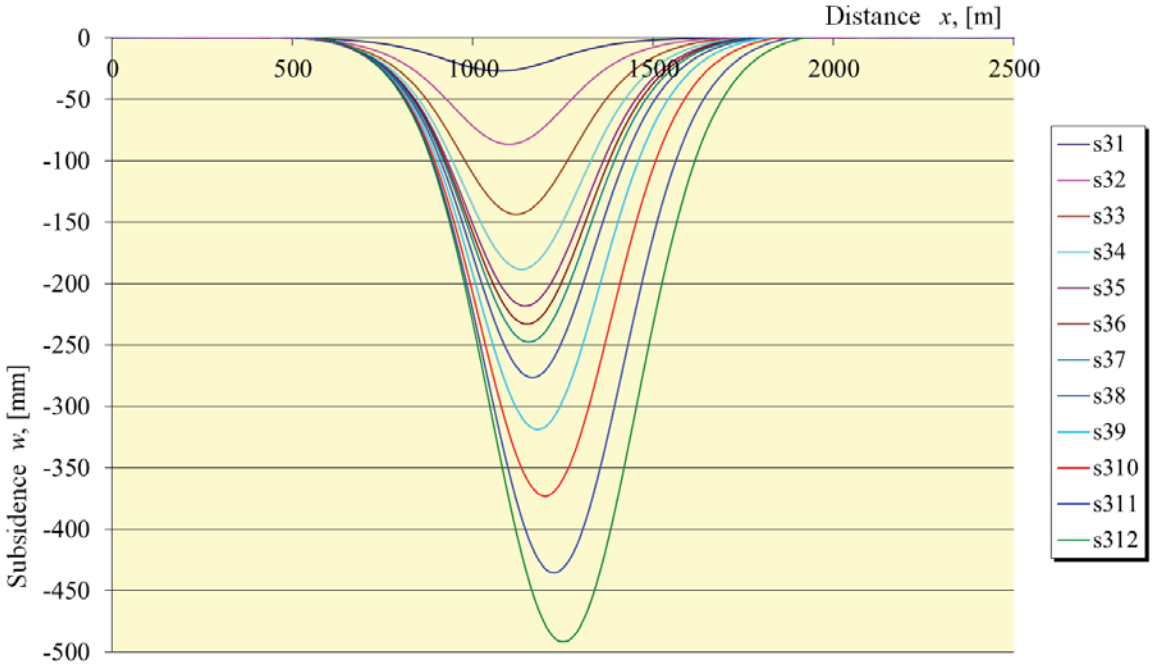

Fig.5. **Evolution of vertical displacement, in the case of the top coal caving longwall mining**
sij: i -number of building levels (i = 3); j - mining sequence (j = 1,2, ..., 12)

Under the same conditions, the *vertical displacement* reaches the maximum value of 491 mm, at the time of entire panel mining, for the X_{ca} = 400m, and in the point where the goaf has a length in the straight direction X_{ca} = 50 m, the subsidence is about of 27 mm (fig. 5).

The size of the subsidence area, measured following the *x* axis of the model, for the first stage of coal seam mining, beginning from 483 m, and reaches a maximum of 1134 m, in the last case of entire panel mining.

3. Assessment of the underground mining impact on a three levels building

3.1. Analysis of the building stability with the aid of Von Mises criterion

This criterion is widely used in the numerical modeling and it is based on that fact that, a material deforms when the potential deformation energy of the body shape reaches a critical value (Mocanu, 1980; Posea, 1979):

$$\sigma_{ech} \leq \sigma_{at} \qquad (1)$$

where:

σ_{ech} represents the equivalent stress of the material;

σ_{at} - allowable tensile strength of the material.

Expression of the equivalent stress is given by the relation:

$$\sigma_{ech} = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1 \cdot \sigma_2 - \sigma_1 \cdot \sigma_3 - \sigma_2 \cdot \sigma_3} \qquad (2)$$

where:

σ_1, σ_2 are σ_3 $(\sigma_1 > \sigma_2 > \sigma_3)$ are the main stresses for the three directions (the maximum, medium and minimum).

Further, the behaviour of a three levels building is analysed, under the influence of a top coal caving longwall mining.

From fig. 6 it is observed that the using of top coal caving longwall mining has an important influence on the maximum stress exerted on the building, which develops in a large range of values and increase powerfully in the same time with coal face advancing.

Starting with second sequence of the coal seam mining (for X_{ca} = 100 m), the maximum stress, to which the building is subject, develops in the range of 7 450 kN/m^2 ÷ 81 600 kN/m^2. In this case, the building is affected especially in the foundation and in the structural parts situated from the coal face, on the first level (fig. 6). After the panel full mining, the main structural parts of the building affected are limited to levels I and II, in the area between foundation and walls, under the windows respectively (fig. 7).

The thick coal seam mining, by using the top coal caving longwall mining method, induces to the building a similar behaviour to that caused by the mining in slices, with caving rocks roof control, mentioning that the variation of the maximum stress generated in the building structure has a more pronounced increasing tendency.

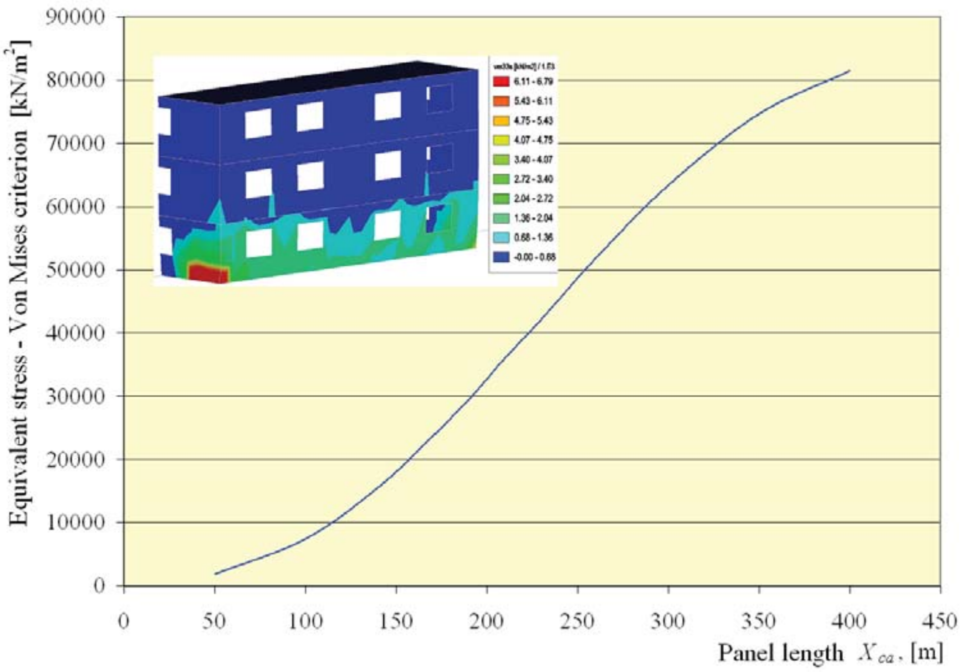

Fig. 6. **Evolution of the equivalent stress, according to Von Mises criterion, in the case of top coal caving longwall mining method, for a building with three levels**

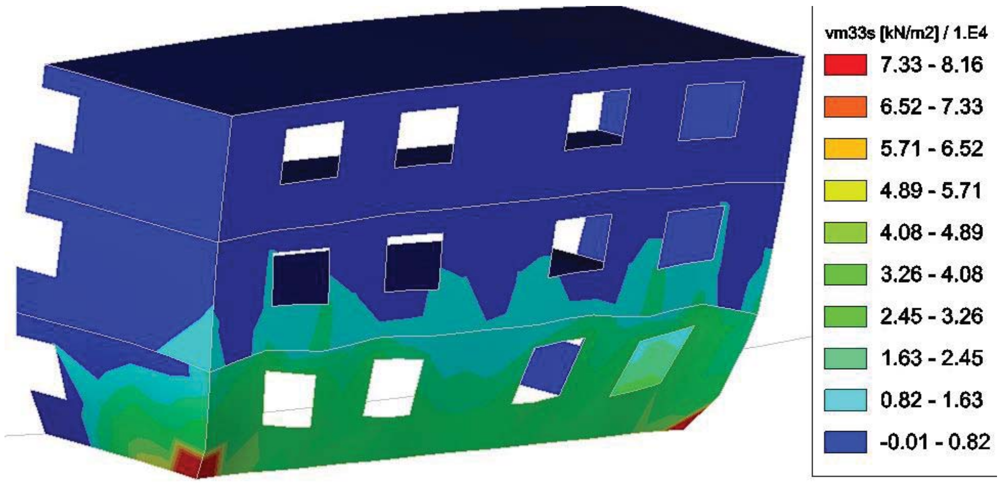

Fig.7. **Damage mode of a building with three levels, according to Von Mises criterion, if the case of using of the top coal caving longwall mining method and for a panel length of X_{ca}= 400 m**

3.2. Analysis of the building stability after the maximum and minimum main stresses

The study of minimum and maximum main stresses development, generated by underground mining on the modelled building structure, revealed that they are influenced directly only by mining system, rather than the loads developed by the building weight.

Assessment of the behaviour of structural building elements under the main stresses action is based on by maximum normal stress theory. Based on this theory, the stability limit condition occurs when the resistance element reaches the maximum main stress at the tensile / compressive simple loading (Mocanu, 1980; Posea, 1979).

If the $|\sigma_1| > |\sigma_3|$, the equivalent stress, after the maximum normal stress theory is:

$$\sigma_{ech} = \sigma_1 \leq \sigma_{at} \qquad (3)$$

iar dacă $|\sigma_1| < |\sigma_3|$, atunci:

$$|\sigma_{ech}| = |\sigma_3| \leq \sigma_{ac} \qquad (4)$$

where: σ_{at}, σ_{ac} is the allowable tensile stress, respectively compressive stress.

The influence of the *maximum main stress* σ_1, of traction, on a building with three levels was studied by analyzing the affected areas in the two moments of mining, namely: when coal face is situate in a second sequence of the model (for X_{ca} =100m) and the case in which the panel mining has been completed. In the first case, which is explained in fig. 8, the main affected areas are the face of the building and the upper and lower corners of windows, in the top two levels of the building, the joining zone of the façade with the sidewalls (both the first level, and the upper level) and the side wall of the building at the first level, closest to the coal face line.

In the second situation, shown in fig. 9, the main affected areas are: the building façade and the upper and lower corners of windows in the top two levels of the building, the joining zone of the building face and the sidewalls, at the first level and at the upper side walls, so at the first level, and the other two levels.

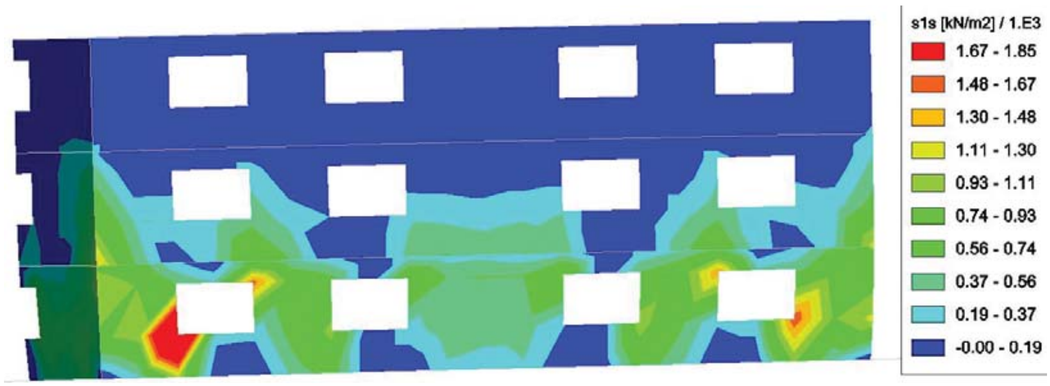

Fig.8. **Maximum main tensile stress distribution, in a building structure with three levels, in the case when the coal face is situated in the second model sequence X_{ca} = 100 m**

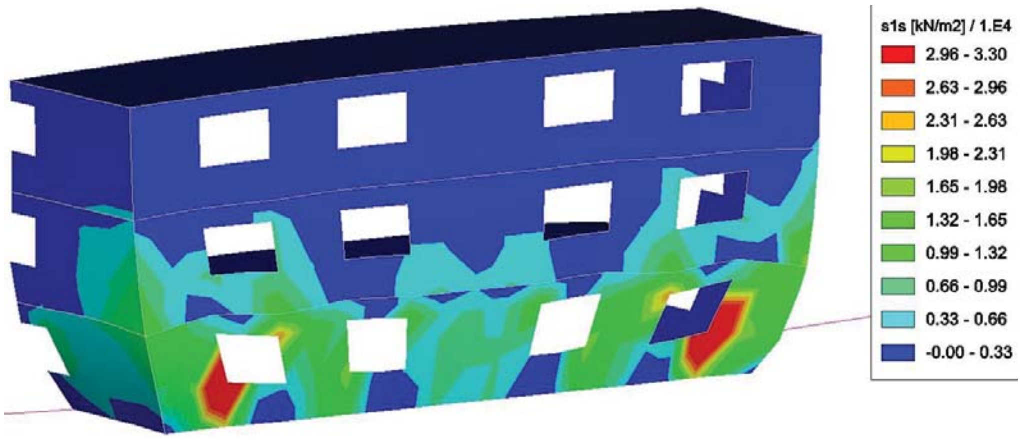

Fig.9. **Damage of a building with three levels, by the maximum main tensile stress, after full panel mining, for X_{ca}= 400 m**

Developing domain of the *main minimum compressive stresses* σ_3, in the structural elements of the building with three levels, as a result of using the top coal caving mining method, has the values ranging in the interval of 7 360 kN/m^2 ÷ 84 600 kN/m^2.

In the case of the top coal caving longwall mining method, when goaf panel length X_{ca} has a value of 100 m, the main structural elements of the building affected by underground mining, are located on the first level of the building (fig. 10) and include: foundation, the window parapet, the lower part of the side wall closest to the coal face line and the joining line between the side wall and the foundation and the building facade.

Minimum main compressive stresses σ_3 are developing in the same time with the coal seam mining advancement, so that the main areas of the building affected are the followings (fig. 11): foundation as a whole, the window parapet, the upper and lower corners of the windows, the ceiling of the first floor level and the partial window parapet of the second level, the joining area of the side walls with the foundation and the building façade.

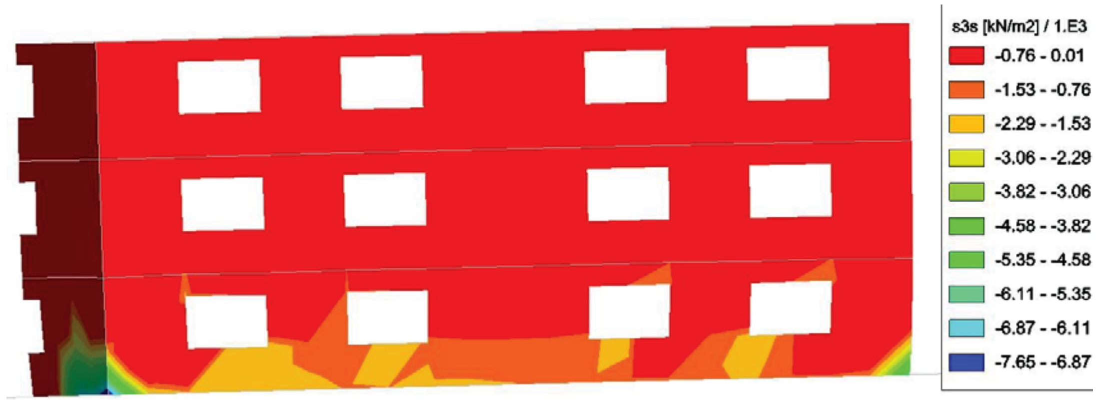

Fig.10. **Minimum main compressive stress distribution, in a building structure with three levels, when the coal face is situated in the sequence two of the model, for X_{ca} = 100 m**

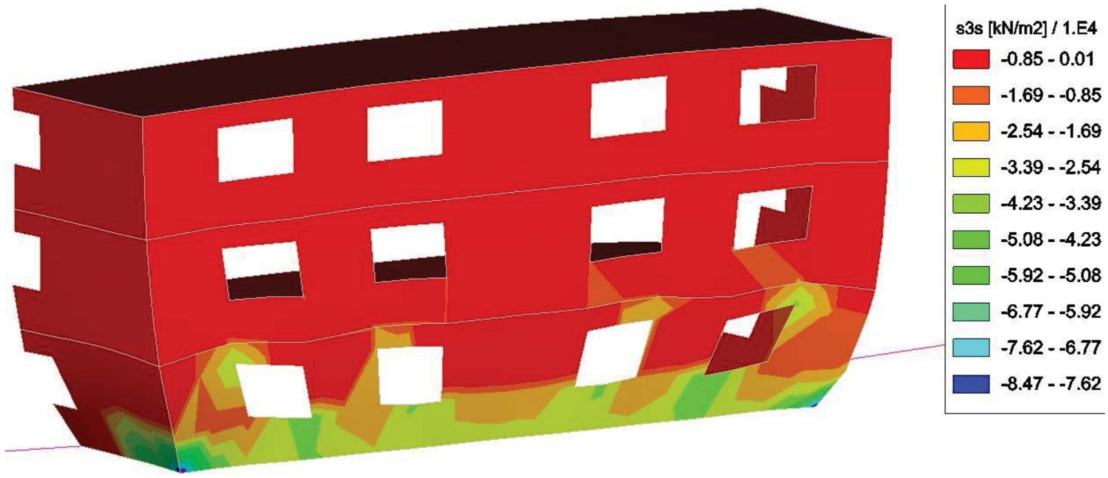

Fig. 11. **Minimum main stress distribution, in a building structure with three levels, in the case of full mining of the panel, for X_{ca} = 400 m**

4. Conclusions

The aim of the researches carried out is to analyze the behaviour of the reinforced concrete buildings with three levels, situated in the influence area of coal seam mining, with top coal caving longwall mining method, in the different coal seam extraction sequences.

To reach the research objectives of a finite elements in 3D modelling was made, using the software CESAR-LCPC, version 4 - processor CLEO3D, of a deposit containing a horizontal thick coal seam with an average thickness of 9m, located at a average depth of H = 300m. Buildings of reinforced concrete, with a level, two and three levels, situated at the surface, had been modelled by the shell finite elements, with a thickness of 0.3 m.

The simulation of the coal seam mining with a longwall face of 150 m of length, in a panel with overall extension of 400 m, was analysed for 12 extraction sequence of the mining panel.

Because of the models with very large sizes (X = 2 500 m, Y = 500 m and Z = 409 m), into a simplified manner, the mediums from the models composition were considered as continuous, elastic and isotropic and the model charging has been performed geostatic, for rock masse and gravitational, for the building.

The results of computations carried out on the 12 models consist of stresses state and vertical and horizontal displacements, for the rocks masse and of specific forces and moments, for the structural elements of the buildings.

From the analysis of ground surface deformation under the influence of the thick coal seam underground mining, results that the extension of the subsidence area, following the axis x, for all the 12 stages of the mining simulation is between 440 m, for X_{ca} = 50m and 1134 m, in the case of full panel mining, for X_{ca} = 400m.

The vertical maximum displacements are of 491 mm and the maximum horizontal displacements ranging between of 136 mm and -136 mm, for a maximum extension of the mined panel of 400m.

According to the Von Mises evaluation criterion of underground mining impact on the building with three levels, the maximum stresses exerted on the building develops in a wide range of values (7 450 kN/m^2 ÷ 81 600 kN/m^2), with a strong upward expressed with the coal face advancement.

From the study of the maximum and minimum main stresses exerted on a building with three levels it was found that both the maximum and minimum main stresses and are developed in a single stage, in the case of top coal longwall mining.

The areas most affected by the maximum and minimum main stresses exerted on the building are the following: upper and lower corners of the windows, the joints area of the walls, the joints between the walls and foundation.

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