3D ANALYSIS WITH FINITE ELEMENTS OF LAND STABILITY AFFECTED BY UNDERGROUND MINING, WITHIN PAROSENI MINING PERIMETER, FOR THE LOCATION OF A MAIN GAS PIPELINE

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Abstract: *This paper refers to the analysis of the land surface deformations generated by the underground mining of the coal deposits within Paroseni mining perimeter, using the 3D finite element modeling. The purpose of the modeling is to optimize the location of a main natural gas pipeline, so as not to be affected by the deformations transmitted to the surface.*

Key words: *numerical modeling, finite elements, subsidence, horizontal displacement, coal seam, underground mining, gas pipeline*

1. Introduction

One of the major projects of the National Gas Transmission Company TRANSGAZ S.A. [8] plans to build a main natural gas pipeline, to cross Bulgaria, Romania, Hungary and Austria (BRUA). The transport route on the territory of Romania is about 500 km long and will cross 11 counties: Giurgiu, Teleorman, Dâmboviţa, Argeş, Olt, Vâlcea, Gorj, Hunedoara, Caraş-Severin, Timiş and Arad. The aim of the project is to diversify European countries' natural gas supply sources and will allow, in the future, the interconnection with the pipelines of liquefied gas from the Georgian Black Sea coast (AGRI project) and gas from the continental shelf of the Black Sea [9].

According to the project, the above-mentioned pipeline must also cross the Jiu Valley mining basin, through a series of unstable areas, affected by the underground mining of coal deposits, while taking into account the presence of some constructions on the surface (Fig. 2).

Fig. 1 *BRUA project on Romanian territory* [9]

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The purpose of this paper is to optimize the location of the main gas pipeline in such a way that it is not affected by the deformations transmitted by the underground mining.

2. 3D finite element modeling

Because 2D modeling cannot effectively detect the superposition effects of two neighboring extracted spaces, the aim of this paper is to perform a 3D finite element modeling using CESAR-LCPC software, version 4, with CLEO 3D processor [3], [4], [5], [6].

In accordance, the disposal of the extracted spaces is as shown in Figure 2 and simplified accordingly with a view to make operable a 3D model with finite elements of a very large size, measuring kilometers.

The 3D finite element model has the following dimensions: X= 3 169 m; Y=3 426 m; Z=580 m.

In the model with finite elements, the extracted deposit is represented by the coal seams 3 and 5, in the conditions of Paroseni mining field, considered continuous, homogeneous and isotropic [4], [5].

The average thickness of seam no. 3 is 12m, while that of seam no. 5 is 3m; seam 5 is at an average depth of H = 407m, measured from the surface to the roof of the seam, while seam 3 is located at an average depth of H = 468m, measured from the surface to the roof of the seam. In order to get significant results, seams 3 and 5 are considered to be extracted in the final phase and the geometry of the extracted areas / panels (Fig. 3), related to the thick seams 3 and 5, generated in the finite element model, is synthesized in table 1 [1], [2].

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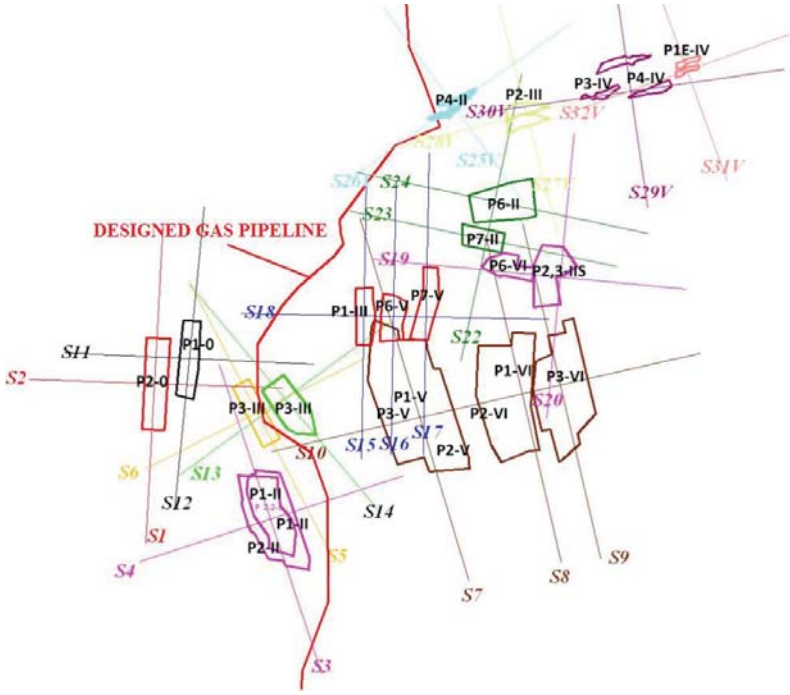
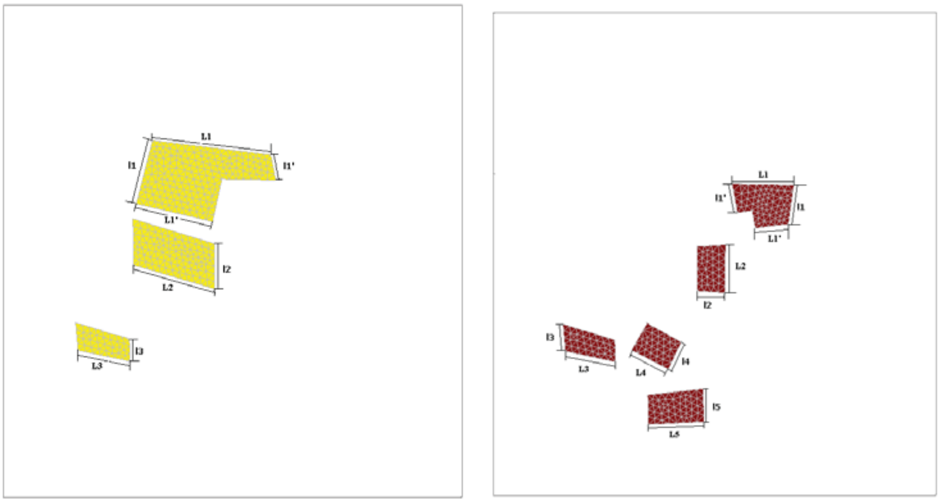
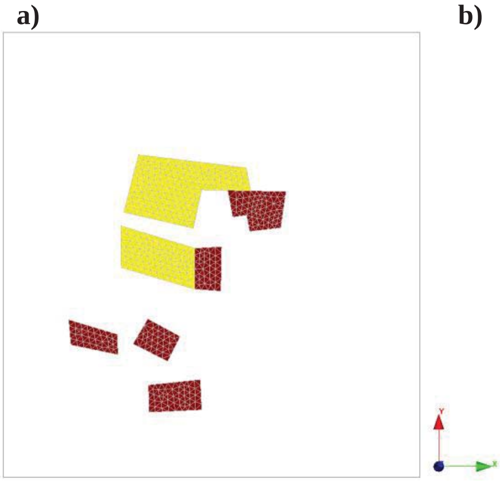


Fig. 2 *The position of the extracted spaces within Paroseni mining perimeter [7]*



a) **b)**



c)

Fig. 3. *Geometry of the extracted areas of the 3D finite element model: a) seam 3; b) seam 5; c) seam 3 and 5 [1], [2]*

Table 1. *Characterization of the geometry of the extracted spaces within Paroseni mining perimeter*

Panel	Seam 3						Seam 5					
	L, [m]		*l*, [m]		h_{ex}, [m]	*H*, [m]	*L*, [m]		*l*, [m]		h_{ex}, [m]	*H*, [m]
	L_1	L_1	l_1	l_1			L_1	L_1	l_1	l_1		
P1	825	542	456	180	12	468	443	238	283	210	3	407
P2	584		316		12	468	342		197		3	407
P3	365		155		12	468	312		206		3	407
P4	-		-		-	-	296		214		3	407
P5	-		-		-	-	401		233		3	407

Observations: *L*, *l* – length, respectively width of the panel / extracted space; h_{ex} – height of extracted space/ extracted coal seam thickness ; *H* – depth of the deposit, measured from the roof of the seam.

Model meshing was performed with triangular finite elements, using a linear interpolation function, which resulted in a number of 38,095 nodes and 71,262 volume elements.

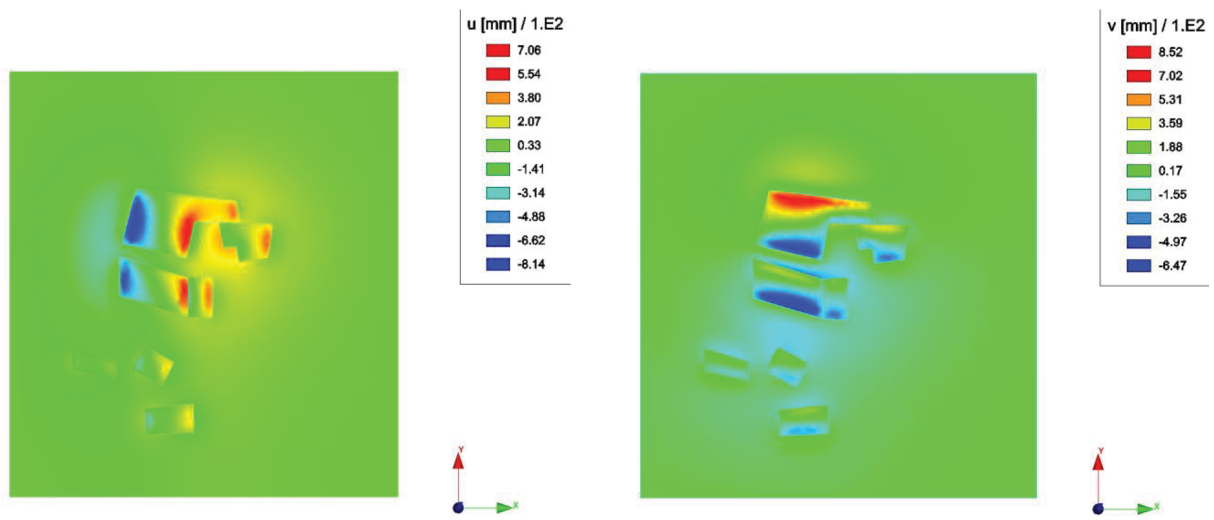
3. Analysis of the results obtained from the 3D numerical modeling

The results obtained from the 3D numerical modeling of the extracted spaces related to seam no. 3 and no. 5 within Paroseni mining perimeter and connected with the phenomenon of surface subsidence due to the underground mining of coal in the area are summarized in Table 2.

Scalar graphical representation of the horizontal and vertical displacements in each extracted panel is presented in Figure 4

Table 2 *Parameters of the subsidence phenomenon generated by the extracted spaces within Paroseni mining perimeter*

Panel	Seam 3			Seam 5		
	***Subsidence w*, [mm]**	***Horizontal displacement u*, [mm]**	***Horizontal displacement v*, [mm]**	***Subsidence w*, [mm]**	***Horizontal displacement u*, [mm]**	***Horizontal displacement v*, [mm]**
P1	1 990	-390 ÷ 582	-289 ÷ 7	815	-293 ÷ -335	-4 ÷ 126
P2	1 430	-306 ÷ 388	227 ÷ 325	1 248	-330 ÷ -265	251 ÷ 301
P3*	343	86 ÷ 121	48 ÷ 81	343	86 ÷ 121	48 ÷ 81
P4	-	-	-	403	-103 ÷ 65	102 ÷ 127
P5	-	-	-	372	-126 ÷ 71	19 ÷ 110



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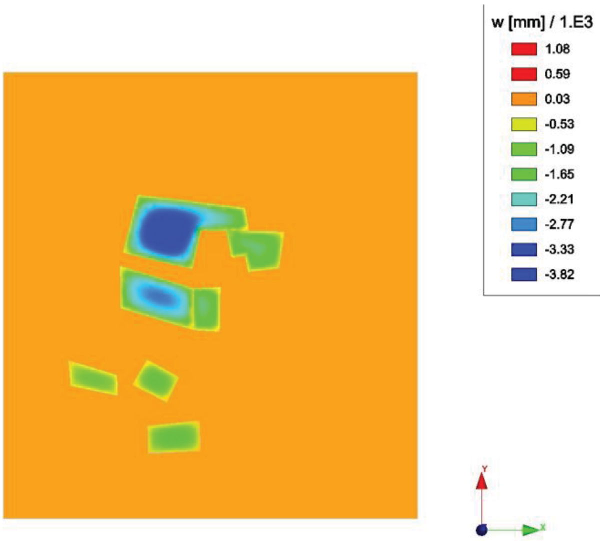

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Fig. 4. *Scalar representation of the horizontal and vertical displacements generated by each extracted space: a) horizontal displacements u, along the x-axis; b) horizontal displacements v, along the y-axis; c) vertical displacements w [1], [2]*

3.1. Analysis of the horizontal and vertical displacements related to route 1 of the pipeline

The analysis of the results obtained from 3D modeling shows that the maximum subsidence reaches the value of -400mm (Fig. 5), the horizontal displacement u, along the x-axis, is in the range of -176mm +170mm (Fig. 6) and the horizontal displacement v, along the y-axis, reaches the maximum value of +158mm (Figure 7) [1], [2].

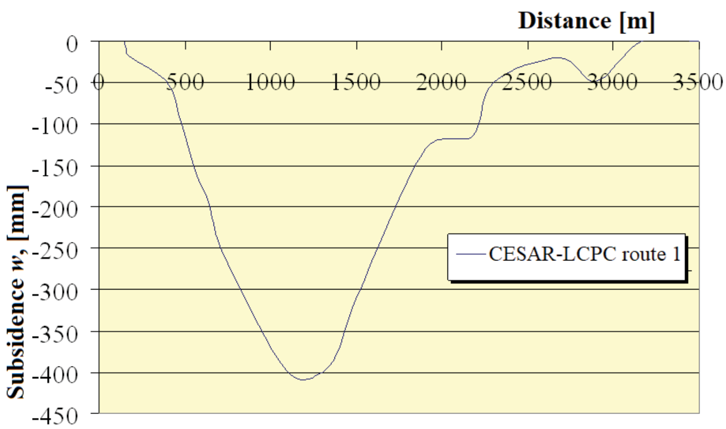

Fig. 5. *Maximum predicted subsidence through 3D modeling on route 1 of the pipeline [1], [2]*

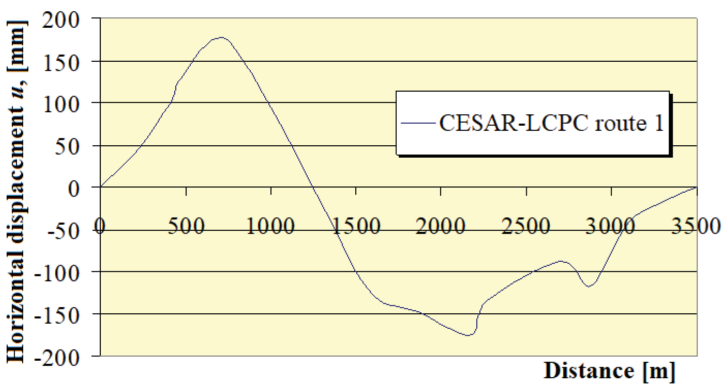

Fig. 6. *Horizontal displacement u predicted through 3D modeling on route 1 of the pipeline [1], [2]*

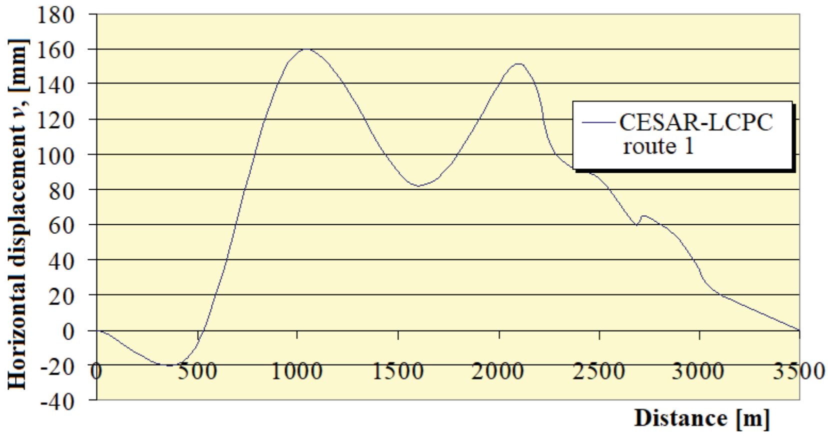

Fig. 7. *Horizontal displacement v predicted through 3D modeling on route 1 of the pipeline [1], [2]*

3.2. Analysis of the horizontal and vertical displacements developed on route 2 of the pipeline

After studying the results obtained from 3D modeling on the second possible pipeline location, the following data were obtained: a maximum subsidence of -290mm (Fig. 8), a maximum horizontal displacement *u*, along the *x*-axis, of 240mm (Fig. 9) and a maximum horizontal displacement *v*, along the *y*-axis, of -354mm (Fig. 10).

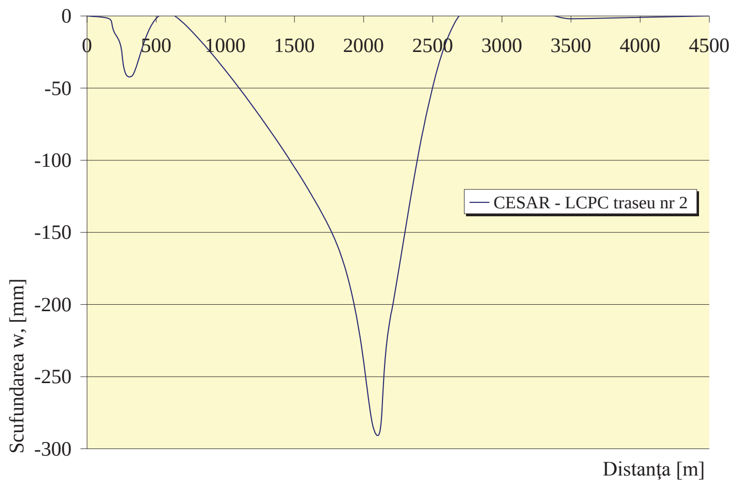

Fig. 8. *Maximum predicted subsidence through 3D modeling on route 2 of the pipeline [1], [2]*

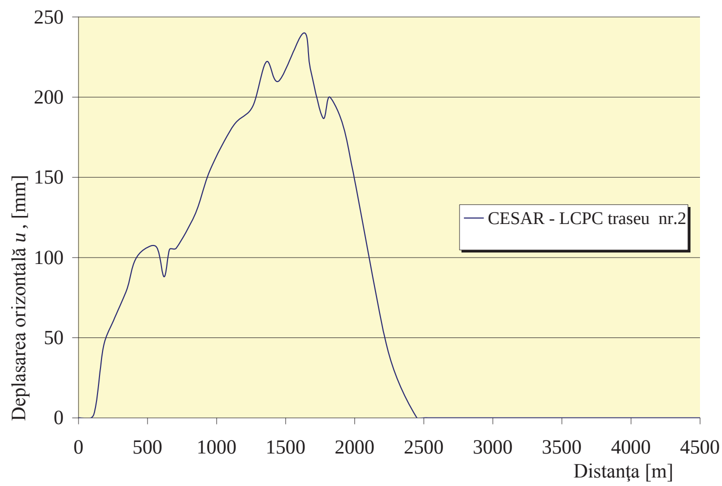

Fig. 9. *Horizontal displacement u predicted through 3D modeling on route 2 of the pipeline [1], [2]*

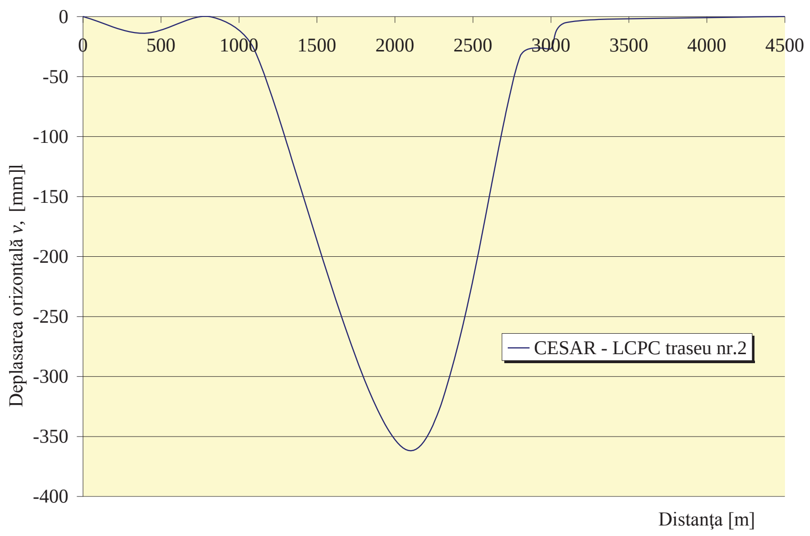

Fig. 10. *Horizontal displacement v predicted through 3D modeling on route 2 of the pipeline [1], [2]*

3.3. Comparative analysis of surface behavior on the two routes chosen for the pipeline location

From the comparative analysis of the data resulted from the numerical modeling, one may infer that there are certain phenomena of land movement, of different amplitudes, along the two analyzed routes [1], [2].

Land subsidence phenomenon, along route 1, occurs almost along the whole route, unlike route no. 2, where subsidence occurs only along 2km, from a total of 4.5km. The maximum predicted values in the case of route 1 are represented by a subsidence of 400mm, while in the case of the second route they are reduced to a maximum of 290mm; the horizontal displacement *u* along the *x*-axis in the case of the first route ranges between -176mm and +170mm and reaches the value of 240mm in the case of the second variant; as far as the horizontal displacement *v* along the *y*-axis is concerned, a maximum of 158mm is reached in the first case and -354mm in the case of route no. 2.

All these data, corroborated with the requirements resulting from the legal provisions related to the design and execution of pipelines for gas transportation (Order 118/2012, ANRE Order 75/2014, General Urbanism Regulation, approved by HG no. 525/1996, etc.) have led to the conclusion that such a construction cannot be carried out within operating perimeters, unless a safety pillar for this construction is placed before mining starts.

However, in the case when it is absolutely necessary to construct such a building, the chosen route will be the one in which land movement is minimal; the project requires the strict topographic monitoring of the chosen route in order to obtain data related to the stability of the environing land.

4. Conclusions

This study had as a starting point the idea of building a main gas pipeline to cross the Jiu Valley mining basin from south to north, having resulted from an important project of the National Gas Transmission Company TRANSGAZ S.A.

With the help of CESAR-LCPC software, version 4 – CLEO3D processor, two three-dimensional models of a part of the deposit of Paroseni mining field, having the following dimensions: X = 3 169m, Y = 3 426m, Z = 580m were carried out. These models were a means of studying the horizontal and vertical displacements that arose from the underground mining of coal seams, according to which the stability of the land and structures affected by the underground excavations was evaluated [1], [2].

The 3D finite elements models display seams 3 and 5 (considered to be the most important ones from an economic perspective), under the conditions Paroseni mining field, the massif being considered as continuous, homogeneous and isotropic. The average thickness of seam 3 is 12m and that of seam 5 is 3m; seam 5 is at an average depth of *H* = 407m, measured from the surface to the roof of the seam, and seam 3 is at an average depth of *H* = 468m.

To achieve significant results, seam 3 and 5 are considered to be extracted in the final phase.

As a result of the numerical modeling of the massif together with the extracted spaces of seams 3 and 5, within Paroseni mining perimeter, a series of data characterizing the horizontal displacements *u*, *v* and the vertical displacement *w* of the surface were obtained.

The analysis of the data obtained shows that such a construction can be located in this mining field without major risks in the case when a safety pillar for this construction is built before mining starts.

Since the design of a safety pillar has not been achieved, the route chosen for the location of such a construction should meet at least two essential conditions, namely: a) surface movements should be minimal (with values closest to zero); b) movements should be monitored before the execution, along the whole construction route.

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