STRAIN AND STRESS ANALYSIS OF THE SUPPORT STRUCTURES OF OCNA DEJ SALINE, LEVEL +157M

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Abstract:
In depth mining of the Ocna Dej rock salt deposit will lead to the rise of instability phenomena of support structures (pillars, rooms and ceilings). In this way, this article achieves a synthesis of the stress - strain analysis and the support structures stability by using the finite element modelling, in conditions of mining with roadheaders of the +157m level.
Keywords: rock salt, underground mining, rooms, pillars, finite elements, numerical modelling, stress, strain

1. Geological and geomechanical characterization of the Ocna Dej rock salt deposit

In the mining perimeter zone there are very old mines that date back to the Roman Empire occupation and continued to exist until present times (Almăşan, 1984; Moldovan, 2010).

Ocna Dej rock salt deposit belongs to the alignment of the western diapir of the Transilvanian depression and it has the quasi-horizontal lens shape (fig.1), developing on about 5km length, following the North-South direction and on the 3.7km width, on the East-West direction. The maximum lentil thickness, of 156m, is at the central zone, which decreases towards the extremes of these, to some meters of thickness. Rock salt lentil has a gentle arching anticline on the North-South direction. General dip of the lentil is toward South (Onica ş.a., 2012; Onica & Marian, 2016).

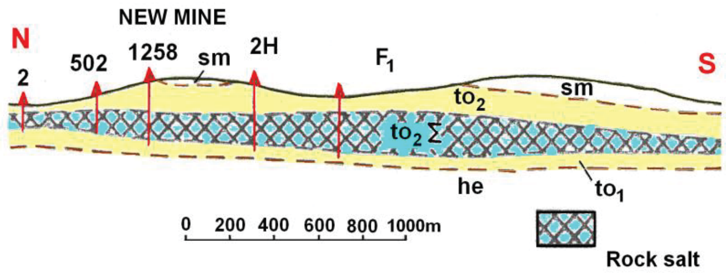

Fig. 1 **Vertical cross-section of the Ocna Dej rock salt massive**
He- helvetien; $to_1\Sigma$ -thortonian rock salt; to_2 –superior thortonian; sm-sarmatian

Thortonian geological formation has the most important extension of zone and is represented by three levels: Dej's tuffs, rock salt level and the marls level with dacic tuffs intercalations (Almăşan, 1984; Moldovan, 2010).

Dej level tuff has about 35m of thickness and a green colour, because of chlorite presence. This horizon characteristic consists in that it contains the water under pressure, leading to the fact that the old mines were prematurely lost and flooded.

Rock salt level has a vertical thickness ranging between 40 and 130m. The rock salt massive presents horizontal stratifications, which created the difficulties in the case of the big rooms mining.

Ocna Dej rock salt massive appears like a lentil prolonged following the North – South direction, with the big axis of about 3.5km, and the small axis of 0.5km, having the thicknesses ranging between 40km (at the margins) and 130m, in the central part. The rock salt lens is not affected by the tectonic disturbances.

In the floor deposit, the Dej's tuff appears, from wear resulting that the Dej rock salt is of Thortonian- superior age.

The hydro-geological conditions of the deposit had a negative influence on the productive activity. Along with the descent of the mining level, the mine flood hazard appears. Therefore, there arises the requirement of the safety pillar from the rock salt massive, in the mining room's floor, of about 20-25m of thickness.

In the year 2012, a researcher team from University of Petroşani (Onica et.al., 2012), that designed the roadheader technology for Ocna Dej rock salt extraction, performed a certain number of geo-mechanical characteristics determination for the level +173m (Hirian & Georgescu, 2012).

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The tests were made on the cylindrical samples, with $d=h=42$mm, respectively on the prismatic samples with the transversal section of 5 x 5 cm^2, samples that were taken from three cubic blocks, with the wedge of 300mm, emanating from mining rooms R14-S14, J14-J15, AS28-AS-29.

The mining method applied at the Ocna Dej saline is with small rooms and square pillars with the following sizes: rooms with the width of 15m and the height of 8m; pillars with the wedge of 15 and the height of 8m; ceiling with the thickness of 7.5m (Onica, 2016a; Onica & Marian, 2016).

In the present, the mining is developed at the level +173m, situated at about 188.5m from the surface. Over that level, two levels were already mined, namely level +204m and +188.5m. Also, over the level +204m, a roof pillar of 35m of thickness was designed, and over this pillar are the rocks including the marls, clays and sandstones with about 115m of thickness. Under the level +173m, another two levels will be mined, namely the level +157.5m (fig.2), situated at 212m of depth by report to the surface and the last level, +142m, situated at 219.5m of depth.

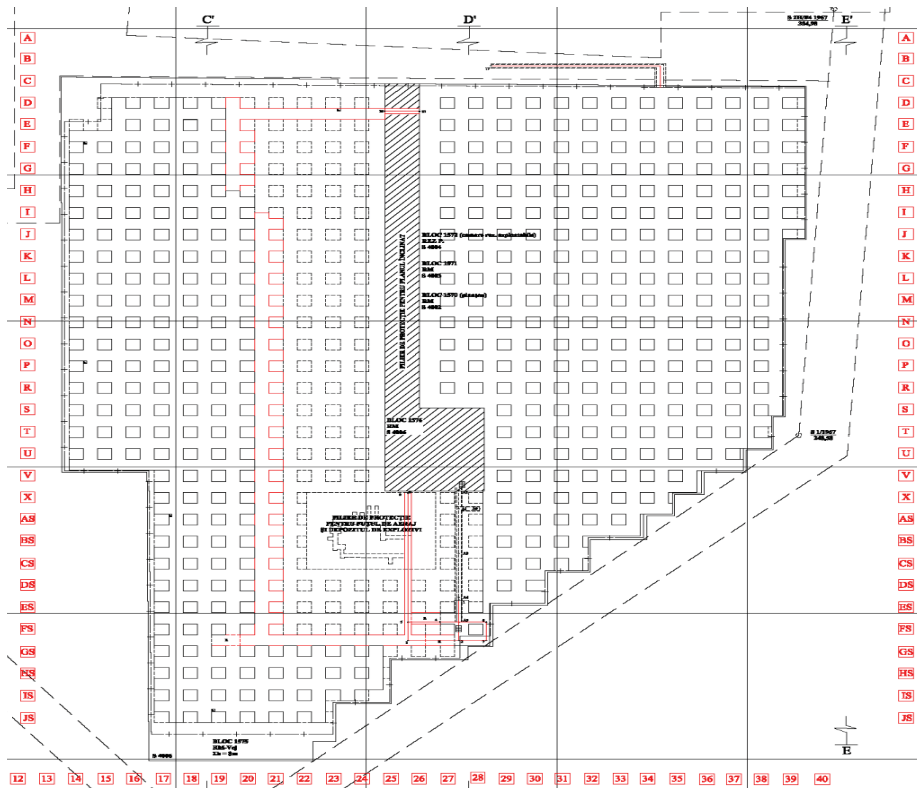


Fig.2 **Rock salt mining with the aid of roadheader at the Ocna Dej saline – West mine, stage 3, level +157m (Onica et.al., 2012)**

2. Models description

The achievement of the computational finite element models in the plain strain and the elastic behaviour hypothesis, was generated in the deposit transversal cross-sections 7-7 (respectively E-W) and C-C (respectively N-S) – in conformity with the situation mine maps.

For carrying up the 2 D models, in the plain strain hypothesis and the elastic behaviour of the rock salt deposit, were made the following simplifying suppositions (Onica et.al., 2012; Onica & Marian, 2016):

The achieved finite element models were performed in conformity with the project vertical cross-sections (longitudinal and transversal), at the maximum mining extension, corresponding with the level +157m (supposedly being the critical situation from the point of view of the underground excavations stability), and which could be generated in the plane strain hypothesis;

The sizes of the rooms, pillars and ceilings are supposed equal on the entire sublevel, and the pillars are considered perfectly coaxial, following the vertical;

Both the surroundings rocks and the rock salt massive are supposed to be continuous, homogenous and isotropic, and the geomechanical characteristics used in the calculus are average ones, representative for the entire rock massive, respectively rock salt;

In situ behaviour of surroundings rocks and the rock salt massive is considered to be elastic type (Poisson ratio $\nu = 0.2 - 0.21$);

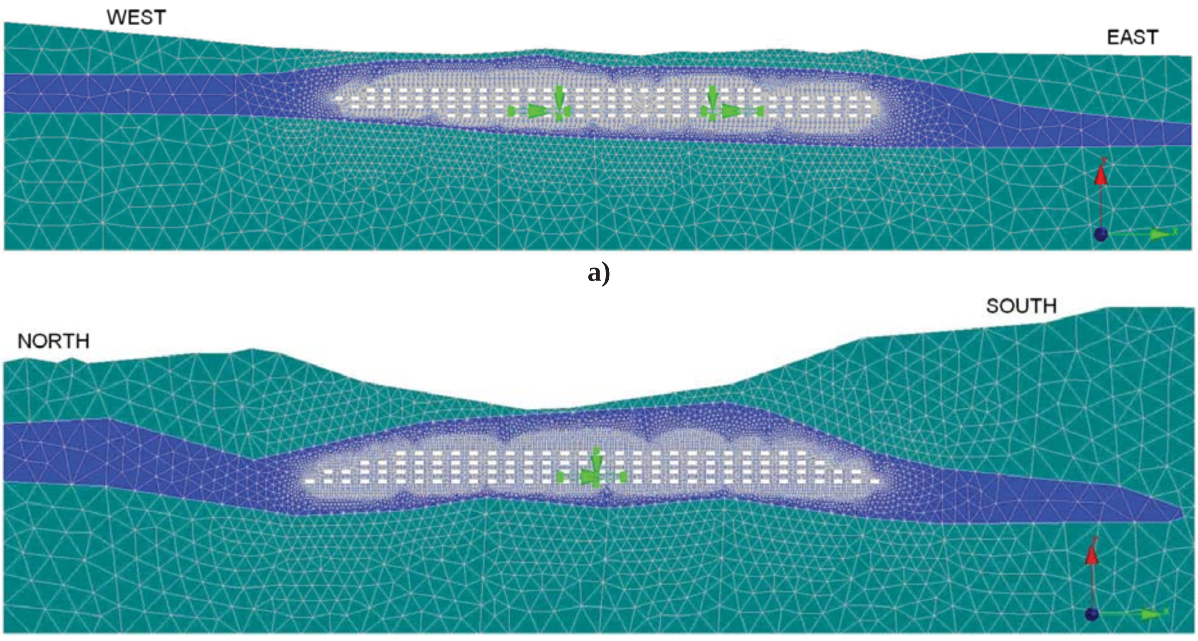
The natural stress state is appreciated to be geostatic.

It was made the model E-W (cross-section “7-7”) with the sizes X=2 222.9m/Y=430.3m and N-S (cross-section “C-C”) with the sizes X=1 963m/Y=541.6m (fig.3). Also, it was established the surrounding underground excavations interest zone (Onica & Marian, 2016).

There were adopted certain medium characteristics, considered by us, as representative for the in situ behaviour of the rock salt and surrounding rocks massive (tab. 1).

Table 1 *Main average geomechanical characteristics of the rock salt massive and the rocks taken into consideration in the finite element modelling*

Characteristic	UM	Value	
		Rock salt	Surrounding rocks
Apparent density, ρ_a	kg/m^3	2 100	2 320
Apparent specific weight, γ_a	kN/m^2	21	23.2
Elasticity modulus, E	kN/m^2	2 200 000	3 700 000
Poisson ratio, ν	adim.	0.2	0.21
Compressive strength, σ_c	kN/m^2	20 000	22 400
Tensile strength, σ_t	kN/m^2	1 300	-
Shear strength, σ_s	kN/m^2	1 800	-
Cohesion, C	kN/m^2	4 000	5 600
Internal friction angle, φ	,^{o}	30	24



b)

Fig.3 **Finite element meshing of the specific models of the Ocna Dej Saline rock salt deposit**
a) Finite element model – Cross-section “7-7” (E-W)
b) Finite element model – Cross-section “C-C” (E-W)

Initial conditions of the model loading was considered as geostatic $[\sigma_o]$, in accordance with a variable thickness of the rocks overburden between about 53.1m and 236.6m, measured from the ceiling of sublevel +204m (in conformity with cross-sections “7-7” and “C-C”).

Mentioning that, the models loading in the plane strain hypothesis (Onica, 2001) simulate the continuous pillars’ existence (for example, the

Praid Saline case), with an infinite length in the "0z" axe direction, perpendicular on the model surface. For modelling the squared pillar existence (in our case of Ocna Dej Saline), respectively the interruptions, because of the existed rooms following the perpendicular direction on the models surface, the models were supplementary loaded by the initial geostatic stresses concentration, with the ratio between rooms and pillars width and pillars one – in our case resulting in a double increase of the models loading.

Therefore, finally, it could be said that obtained results, after running the calculus, must be interpreted thus (Onica & Marian, 2016):

- the stress-strain state values and specific pillars deformations could be considered as real;
- because of the destressing of the ceilings situated between the levels, by their detachment from the continuity of the rock salt massive, the specific parameters values of the ceilings (stresses and displacements) could be considered rather correct and taken into stability analysis;
- because of the loading doubling, in order to obtain an approximately real image about the pillars' stability, the stress-strain state surrounding the mined zone (over the rooms ceiling at the level +204m and the floor of the level +157m and out of the mining limits, from the North to South and from the East to West) is doubled, and the stability analysis of the stresses and the displacement is corrected, by reducing the values by 50%.

3. Results analysis obtained from the numerical modeling

In view to assess the stability of the rooms, pillars and ceilings afferent to the level +157m, it was taken in analysis the rooms stability at the centre of the Western wing, respectively Eastern of the model "cross-section 7-7" (E-W) and the rooms from the centre of the model "cross-section C-C" (N-S), considered as being in the most critical situation from the point of view of stability. In this way, there were provided horizontal sections at the ceiling level (floor of the level +173m and ceiling of the level +157m).

It will be taken into analysis a failure criterion, starting from the rocks characteristic curve. For some point, characterized by a certain stress state, it is determined the corresponding Mohr circle that will be reported at the rock salt characteristic curve. In this way, it will be taken in consideration the Mohr-Coulomb line (defined by the relation: $\tau = C - \sigma \cdot tg\varphi$) and will be established the following conditions: a) If the $\sigma_1 < R_t$, for the $R_1 = \left(C \cdot ctg\varphi - S_c\right) \cdot \sin\varphi$ results $CS = R_1 / R$. b)If $\sigma_1 \geq R_t$, then CS=0; where: $S_c = \frac{\sigma_1 + \sigma_2}{2}$ represents the Mohr circle abscissa; $R = \frac{\sigma_1 - \sigma_2}{2}$ – Mohr circle rayon; R_1 – Mohr circle rayon tangent to the Mohr-Coulomb line; CS – safety coefficient; R_t – rock salt tensile strength; C – cohesion; φ -internal frictional angle.

Concerning the calculated value of the safety coefficient *CS,* there are three stability cases:

1) CS=1, when the Mohr circle and the characteristic curve are tangents – resulting a limit stability;
2) CS<1, when the Mohr circle and the characteristic curve are secants – resulting the conditions for arising the failure phenomena;
3) CS>1, when the stress state is faraway from a failure phenomenon – resulting a certain stability degree, in function of the safety coefficient value.

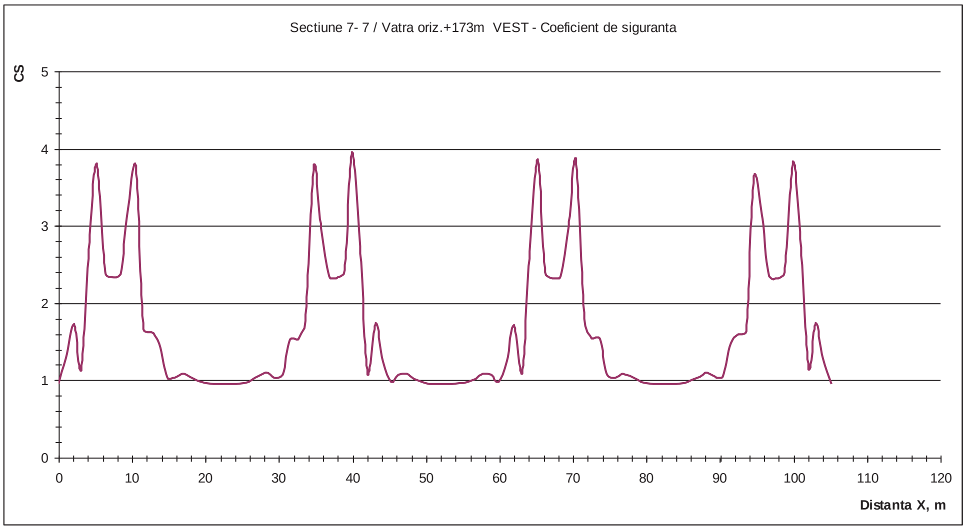
In our case, to appreciate the room stability following their interior contour and implicitly for the calculus of the safety coefficient *CS* (when: C=4 000kN/m^2 and $\varphi = 30^o$), the relation exists:

$$R_1 = 3464{,}102 - 0{,}5 \cdot S_c \qquad (1)$$

The calculated values of the safety coefficients in the different horizontal sections (inside the ceiling, between the levels +173m - floor and the +157m - roof) are represented graphically in the figures 4, 5 and 6.

Analysing the safety coefficients variation in the ceiling between level +173m and +157m, results that the ceilings are in a good stability state toward their centre – safety coefficient is approaching 4 (at the floor of the level +173m) – and towards 6 (at the roof of the level +157m) – see the graphics from the previous figures; the values suddenly decrease at the limits with the rooms walls, towards the stability limit, existing local conditions of rock salt pieces detaching from the rooms' roofs, at a distance of about 1m from the walls. But, as can be seen from the vertical cross-sections, the safety coefficients at that level increase at 1.4 toward the ceiling centre, practically there non-existing a real danger of collapse (by shear or tensile), except only when there are major fissures in the structure of the rock salt massive.

Regarding the safety coefficients variation at the rooms walls, it is noted that they are under the safety limit and can reach values up to 0.7, which could explain the occurrence of rock salt exfoliation after external surface of the pillars and their corners (due to the concentration of stresses in these areas).



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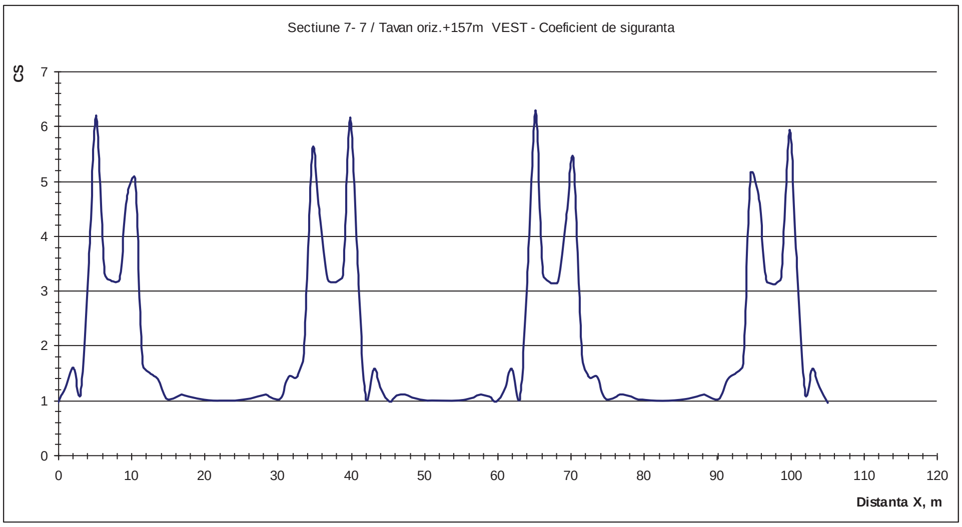

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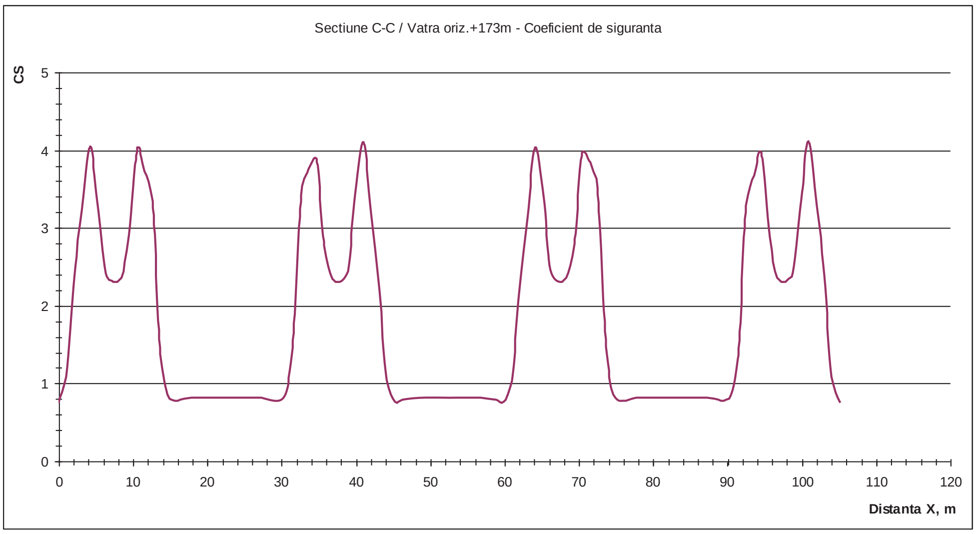
Fig.4 **Variation graphics of the safety coefficients inside the ceilings between the levels +173m and +157m, section "7-7" (E-W): a) floor level +173m West; b) roof level +157m West (are similar for the floor level +173m East and roof level +157m East)**



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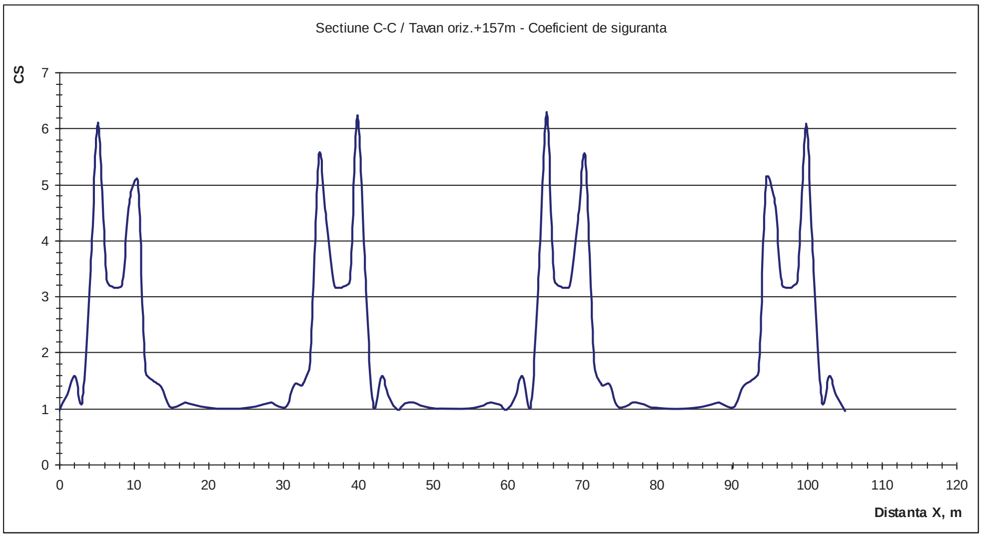

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Fig.5 **Variation graphics of the safety coefficients inside the ceilings between the levels +173m and +157m, cross-section "C-C" (N-S): a) floor level +173m Centre; b) roof level +157m Centre**

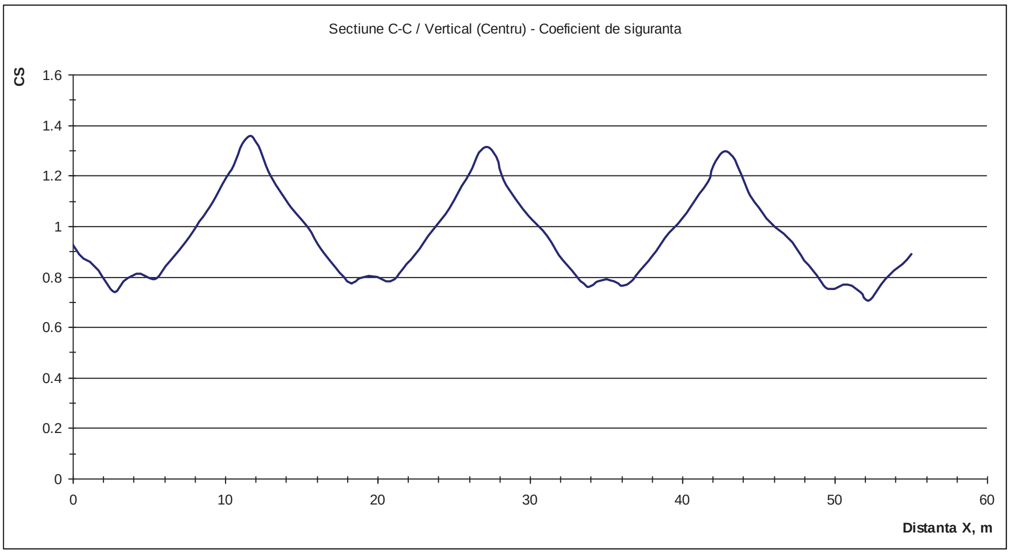

Fig.6 **Variation graphics of the safety after a vertical plane (rooms wall) between the levels +204m (roof) and +157m (floor): cross-section "C-C" – Centre (for the section "7-7" Western and Eastern wing being similar)**

As a *conclusion*, immediately mentioning that "drilling and blasting" technology contributes substantially to a superficial failure of the pillars, over 0.6 m of depth, and the limit conditions of support structure stability (floors and pillars), cutting the rock salt massive with the "roadheader" would contribute substantially to their stability improvement.

Next, using the database (calculation results) obtained from the finite element models generation and the calculus in elasticity, in the plane strain hypothesis, we will make some brief stability analysis regarding the support structures (pillars and ceilings) and mining rooms, afferent to the + 157m level, which is the subject of this mining project. Also, on the level + 157m will be studied, particularly, rooms' stability from the models corresponding to the cross-sections "7-7" and "C-C", considered to be situated in the most difficult conditions.

The *horizontal displacements* of the ceiling between levels + 157m and 173m and the pillars are a maximum of $\pm$ 20 - 40mm.

Regarding the vertical *displacements* (fig. 7), they are all positive under the floor of + 157m level (floor swelling) and negative above the ceiling of this level (subsidence). This means that, because of the fact that the rock salt deposit is mined in four sublevels, on a relatively large depth (55m), a floor and pillars supports swelling was produced from

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the level + 157m (ceiling rooms suffering a maximum vertical convergence of about 50-70mm). At the floor rooms of level + 157m there is an upward vertical displacement (swelling) of about 30-50mm, regarded as 50% of the resulting values from the calculation (which signify a relative vertical room's convergence of 80-120mm).

From the stresses analysis, it is obvious the stresses concentration at the limits between the ceilings and pillars.

Analyzing the *shear stresses* (fig.8), it appears that they exceed at least 8-10 times the rock salt shear strength value (which is of about 1 800kN/m^2) in the room's corners and walls, where could arise the rock salt shear phenomena (respectively, of rock salt detachments from the rooms walls, a phenomenon more obvious towards the room's corners). We mention that, although the ceilings have a relatively good stability, rock salt detachment from room walls are the most common degradation phenomena of the support structures, because of the failure phenomena due to rock salt shearing.

Tensile stresses (fig. 9) are clearly overcoming with over 2 times the rock salt tensile strength in the room's floor at the level + 157m, where the most prominent swelling phenomena occur.

As expected, *compression stresses* (fig. 10) are more important in the inter-rooms pillars, with a significant concentration towards the rooms walls of the level + 157m, from about 16 000kN/m^2 at centre pillars, surpassing the rock salt compressive limits strength in the contact areas with floor and ceiling.

4. Conclusions

From the above analysis can be synthesized, immediately, the following conclusions (Onica, 2016b):

a) On the level + 157m, which is due to enter into mining in the near future, it can be appreciated that the ceiling and floor rooms will have a good stability, but detachment phenomena of rock salt from the rooms walls may appear (mainly due to shear stresses) - stronger at the limits between pillars and ceilings;

b) Taken into consideration the support structures stability at the limits, from level + 157m, the roadheaders use, in the rock salt cutting technological process, compared to explosives cutting, gives support structures the ability to increase stability conditions;

c) Regarding the depth mining of the Ocna Dej rock salt deposit, under the level + 157m (respectively at the level + 141m), we believe that a detailed study is required to reconsider the rooms and pillars sizes. We appreciate that, the continued mining, under level + 157m, preserving the current sizes of the support structures, will implicitly lead to the fall of more than 20-30% of the safety factor, at least at the external surface of the pillars – thus, the stability conditions of the support structures will be worsened.

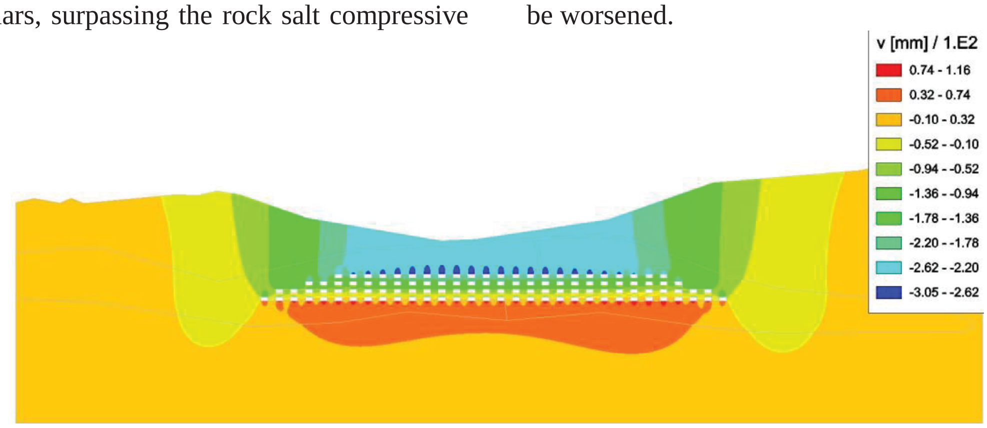

Fig. 7 **v displacements, in mm - scalar representation cross-section NORTH-SOUTH (C-C)**

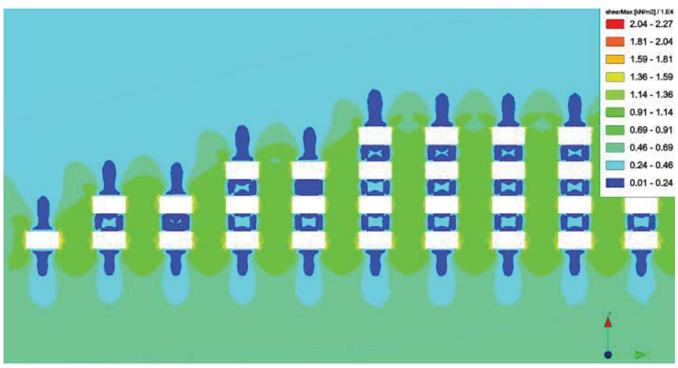

Fig. 8 **Maximum shear stresses $\tau_{f\,\max}$, in kN /m^2 - scalar representation NORTH**

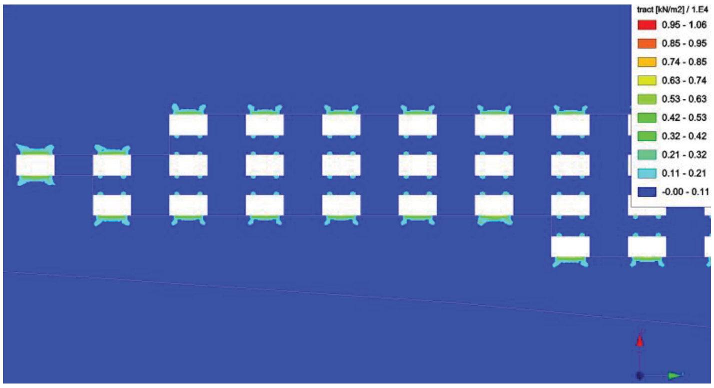

Fig. 9 **Tensile stresses σ_t, in kN/m^2 - scalar representation WEST**

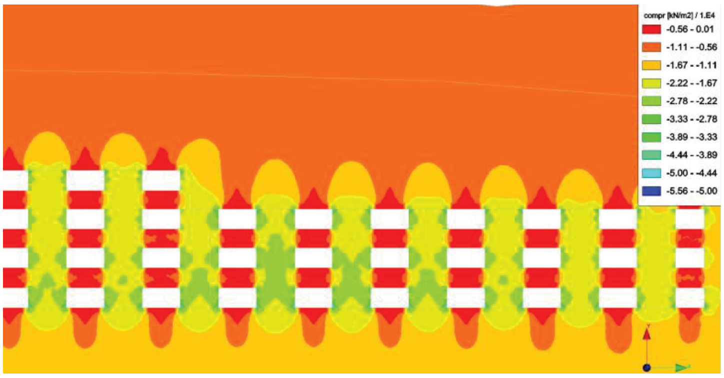

Fig. 10 **Compression stresses σ_c, in kN/m^2 - scalar representation EAST**

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