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Geotechnical Investigations on the Landslide Which Affected Gases Well 2 Prod (Transylvanian Basin)

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Abstract

The paper presents geotechnical investigations performed in the landslide zone which affected column casing of the gases well 2 from Prod structure (Sibiu county) where S.N.G.N. ROMGAZ S.A. Mediaş is in business. For land stability estimation being uses a graphical Swedish method (Fellenius method).

Key words: *landslide, land stability estimation, Fellenius method, well 2 Prod, Transylvanian Basin*

1. Introduction

From a regional-geomorphologic point of view the location of the gases well 2 Prod is on the Târnava Mică Hills, on the eastern slope of a promontory oriented North-West – South-East and belonging to Dealu Mare, having the characteristics of an interriver, between the rivulets Prod and Pârâul Morii (northern affluent of the river Târnava Mare), which descends pericline ending towards Târnava Mare. As far as location is concerned the land of gases well 2 Prod is situated on the eastern side of the above mentioned hill (fig. 1), having a slope of about 4–5° while about 200m upstream the slope increases to 20–30º, and downstream at about 50m the promontory end with slopes of about 30–35º. The area looks like a sliding convexity of high dimensions with an extremely contorted structure with slickensides and a mixture of soil and sandy clays and yellowish clayey sands up to a depth of 10m, with landslide planes at a depth of about 15–20m, the zone needing some works for improvement and consolidation of the land/ground belonging to well 2 Prod. The lithology of clayey sands and sandy clays superposed on silty-calcareous clay, grey-bluish, with a low permeability facilitates the landslide planes with the circulation of underground waters at a depth of 15–20m.

From a structural-geological point of view, the investigated area is situated in the central south-eastern side of the Transylvanian Basin, in the stratigraphical context of outcropping of some Pannonian deposits. The Pannonian contains at its base a rather clays bed in which one finds *Congeria banatica* R. Hoernes and *Paradacna lenzi* R. Hoernes (the inferior boundary is marked by the presence/benchmark of Bazna tuff = ash-coloured tuff, a few centimetres thick, accompanied by foliated clays suprajacente to a bed series of marly clays, coloured grey-blue or appears rubanate with white lamines of calcite) and there develops a sand bed having at its top marly intercalations with *Congeria subglobosa* Partsch, *Congeria partschi* Cžižek, *Congeria zsigmondyi* Hal., *Melanopsis vindobonensis* Fuchs, *Melanopsis fossilis* Gmelin (about 200m of sand interbedded with marly clays and marly limestones with a few layers of sandstones followed by 10m of marly limestones, Ighiş tuff, 150m of marly clays with intercalations of sand, 80m of marls with an intercalation of the conglomerates, 10m of marly limestones with an intercalation of tuff with congeries and *Melanopsis* and at the top with 80m of marly clays interbedded with sands and then conglomerates.

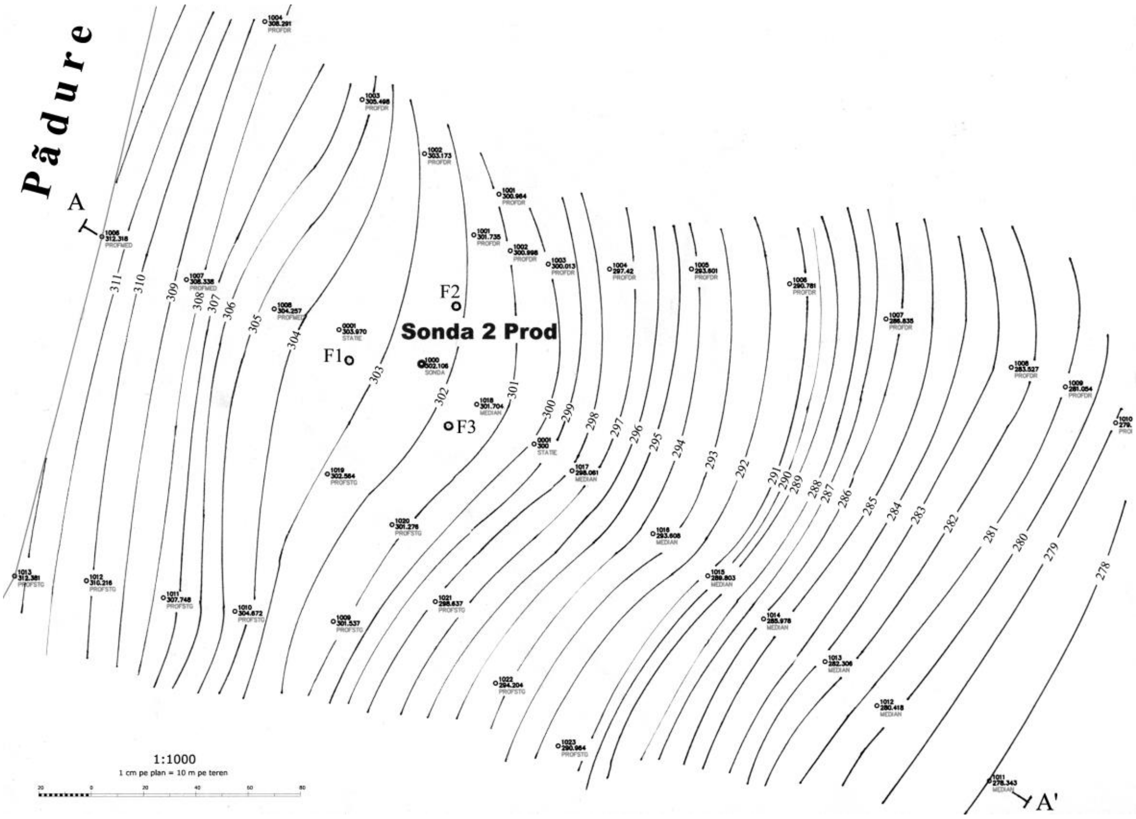

Fig. 1. Geomorphological plan of the location of a well 2 Prod.

2. Determining the depth of the landslide plane

By analysing the samples extracted during the geotechnical drillings, it could be noticed that the slided mass was strongly contorted, with frequent slickenside and that it was made up of sandy clays and clayey sands, even soil at a depth of 7–10m. The sandy clays and clayey sands from the slided mass have big porosities ranging between 33% and 50% and high permeability which facilitate the infiltration of water through the slided area and the growth of the saturation up to 100% in some areas.

The growth of the saturation rate led to the decrease of the angle showing the internal friction (φ) and of these rocks cohesion (*c*), which explains their high rate of mixture (moulding). In some samples there were also identified rolls of white-yellowish smectic clays, with a great plasticity, which favoured the sliding process and the mixing process of the slided mass.

At the depth of 15.50m in F2 drilling (fig. 2), 17m in F3 drilling and 20m in F1 drilling there was found an ash-coloured clay, slightly calcareous (10–12% $CaCO_3$), sometimes silty, fine, hard, compact and which becomes plastic in contact with water, the layer surface of this clay becoming a landslide plane for the mass of sandy clays and clayey sands from above.

The examined samples of rocks indicated at these depths very high humidity (92–96%). Under these circumstances the internal friction angle and the cohesion of the clay decrease almost to zero (φ = 4–8º and c = 1.5–6kPa), the consistency being reduced to soft.

Fig. 2. F2 drilling profile (landslide plane at 15.50m depth).

Apart from this, the indices of activity I_A = 1.38–1.66 > 1,25 which indicates very active clays, rich in smectic minerals, which brings about swelling-contraction effects and thus helps the fluidization of clays and implicitly the reduction of the internal friction angle and of cohesion.

The samples of grey clay from a depth of more than 20m, although they were taken in inadequate conditions because of contamination with drilling fluid, show good and very good geotechnical properties for the high humidity they have (S_r = 0.80–0.95). The granulometric composition and the geotechnical properties of the grey clay under the landslide plane remain invariable over the whole investigated depth (20m) which presupposes continuity at depths more than 40m.

We can conclude that the grey clay is the support for the landslide, the sliding taking place on its surface. The landslide plane has a cycloidal shape (almost cylindrical) and intersects well 2 Prod at the depth of maximum 20m.

For the confirmation of the depth of the landslide plane, the graphical Swedish method was used (Fellenius method or the strips method), which is also a method for estimating the stability of versants and slopes. For the graphical determination of the landslide plane there was built a section (fig. 3) that started from the cleaving place of the landslide (the hill from west) and went through the well 2 Prod, reaching the base of the landslide.

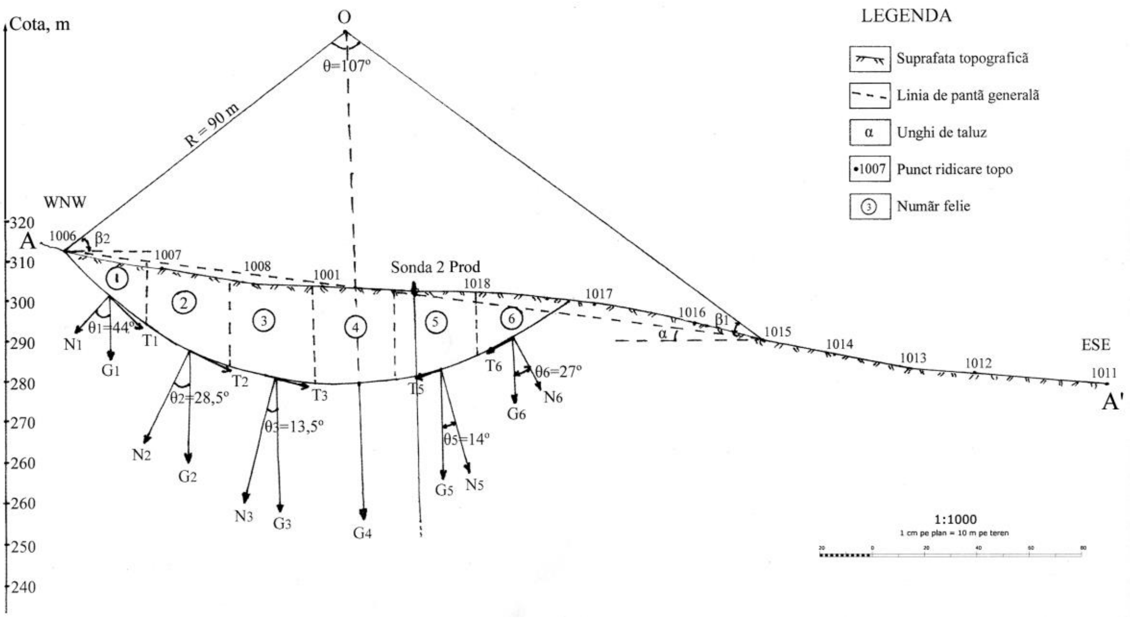

Fig. 3. Determining on the graphical Swedish method of the depth to the landslide plane which affected well 2 Prod.

From the difference in rate between the extreme points of the sliding (1006 and 1015) there results a general slope with an angle α = 11º30'. From the tables, the function showing the value of the sliding angle α one determines the angles β_1 and β_2, and with their help one can find the centre (*O*) of the landslide plane, considered to have a cylindrical shape with the radius *R* = 90m.

From this construction it follows that in the area of the well 2 Prod the landslide plane is placed at a depth of about 20m. The slided mass (in profile) was divided into 6 strips having a width (b_i) of 21m each, the sixth landstrip being 22m wide. Considering the land strips as having a 1m width and average heights (h_i) measured on the axis of the strip, it was calculated the weight G_i for each landstrip. By projecting the force G_i on the surface of the landslide plane there results two components: N_i = the normal component and T_i = the tangent component. h_i = the height of the landstrip and b_i = the width of the landstrip. The thickness of the landstrip is considered 1m.

γ_{med} = 19,295tf/m^3 – calculated as a weighted mean with the thickness of each lithological interval above the landslide plane.

Forces T_1, T_2, T_3, are sliding forces (+).

Forces T_5, T_6, are resistance forces that oppose sliding (-).

Forces $N_1 - N_6$ from all the strips oppose the sliding (-) as a result of the friction and cohesion forces.

Table 1. Calculating elements on landslide plane.

Landstrip no.	h_i **(m)**	b_i **(m)**	θ_i **(º)**	G_i **(t)**	N_i **(t)**	T_i **(t)**
1	11	21	44	4,457.1	3,204.66	3,093.23
2	20	21	28.5	8,104	7,115.31	3,865.61
3	24	21	13.5	9,724.7	9,452.4	2,265.86
4	23.5	21	0	9,522.1	9,522.1	0
5	19	21	14	7,698.7	7,467.74	- 1,855.39
6	10.5	22	27	4,457.1	3,971.28	- 2,019.07

The resistance to shearing on the landslide plane is obtained with Coulomb's equation:

$$\tau = \sigma \mathrm{tg}\varphi + c \tag{1}$$

where: τ is the resistance to shearing on the landslide plane; σ is the normal pressure on the landslide plane (N_i); φ is the internal friction angle (determined by the lab analyses on the samples taken during the drilling). We consider φ = 6º (this value being determined in sample 5 taken from a 15.50m depth and at this depth the landslide plane was estimated during the geotechnical drilling F2). c is the rock cohesion. We consider c = 5.10kPa – value that resulted from the lab analyses.

The resistance to shearing on the landslide plane is:

$$\tau = \left(\frac{N_i}{l_i} \mathrm{tg}\varphi + c \right) l_i \tag{2}$$

$$\sigma_i = \frac{N_i}{l_i} \tag{3}$$

l_i – the length of the landstrip on the landslide plane.

The certainty value of the sliding gradient is:

$$\eta = \frac{M_r}{M_a} \tag{4}$$

where: M_r is the moment of resistance forces; and M_a is the moment of landslide forces.

The moments of the forces are considered in relation to the centre „O" of the landslide plane.

The moment of the resistance forces is:

$$M_r = (\mathrm{tg}\varphi \sum N_i + c \sum l)R = (\mathrm{tg}\varphi \sum N_i + cL)R \tag{5}$$

where: $L = \sum l$ is the total length of the landslide plane; R = 90m; c = 0,51tf/m^2; M_r = 391.558,5tf·m.

The moment of the slide forces is:

$$M_a = R \cdot \sum \pm T_i = 481.521{,}6 \text{tf} \cdot \text{m}. \quad (6)$$

The coefficient of assurance of the slope is:

$$\eta = \frac{M_r}{M_a} = \frac{391.558{,}5}{481.521{,}6} = 0{,}813 \quad (7)$$

Having a subunit value, there results that the sliding mass is unstable, its movement taking place downstream with low speed; this speed can increase together with the rise of the humidity rate in the landslide mass.

From the analyses of the consistency rate of the sliding rocks there results together with the decrease humidity, the consistency (cohesion) rapidly increases, becoming hard if the humidity value of the rocks S_r reduces to less then 0.75%.

From profile one can notice that the gases well 2 Prod stands a pressure given by the landslide components T_1, T_2, T_3:

$$\sum T_i = T_1 + T_2 + T_3 = 9.224 \text{tf}. \quad (8)$$

Over the anchoring casing column of the well, which has a diameter of 600mm, this landslide creates a pressure

$$P = (T_1 + T_2 + T_3) \cdot S \quad (9)$$

where: S = the area (in profile) of the anchoring casing column + the cementation ring.

$$P = 9{,}224 \text{tf x } 0.6 \text{m} = 5{,}534.4 \text{tf/m}^2 = 5.534 \text{kg/mm}^2 \quad (10)$$

But at a level of the landslide plane the well casing column supports a shearing effect caused by the two moments of sliding (M_a) and of resistance (M_r), with much higher values so that at this level the casing column sheared itself.

3. Conclusions

From a lithological point of view the geotechnical drillings in this area clearly showed a thick sedimentary material produced by deluvial processes of about 15–20m consisting in yellowish clayey sands and sandy clays, very moist up to saturation, with high plasticity, usually with soft consistency and which at about 20m below pass into grey clays, slightly calcareous, compact, with hard consistency, which become very plastic by moistening.

The landslide plane was found at the depth of 15.50m in F2 drilling, 17m in F3 drilling and 20m in F1 drilling. At these depths was found an ash-coloured clay, slightly calcareous (10–12% $CaCO_3$), sometimes silty, fine, hard, compact and which becomes plastic in contact with water, the layer surface of this clay becoming a landslide plane for the mass of sandy clays and clayey sands from above.

For the confirmation of the depth of the landslide plane, the graphical Swedish method was used (Fellenius method or the strips method), at the same time being determined the stability value of the landslide mass.

The subunit value proves that the landslide mass is unstable, its movement taking place downstream with low speed; this speed can increase together with the rise of the humidity rate in the landslide mass.

Over the anchoring casing column of the well 2 Prod ($\Phi_{anchoring\ casing\ column} \approx$ 600mm), the landslide manifests a pressure P = 5,534.4 tf/m^2. But at a level of the landslide plane the well column supports a shearing effect caused by the two moments of sliding (M_a) and of resistance (M_r), with much higher values so that at this level the casing column sheared itself.

From the analyses of the consistency rate of the sliding rocks there results together with the decrease humidity, the consistency (cohesion) rapidly increases, becoming hard if the humidity value of the rocks S_r reduces to less then 0.75%. Under these circumstances it is advisable that the rain water should not get into the sliding mass. To this end made-up draining is necessary, both in the upper zone of the splitting and in the side zones.

For repairing the well casing column it is necessary to stop the movement of the sliding mass in the respective area. To this end we suggest that on the southern and northern sides of the equilateral triangle (F1, F2, and F3) to start the drilling and cementation of some casing columns made of steel pipes at a depth of at least 30m.

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Rezumat

În lucrare se prezintă investigaţiile geotehnice efectuate în zona alunecării de teren care afectează coloana de burlane a sondei de gaze 2 de pe structura Prod (Bazinul Transilvaniei). Pentru estimarea stabilităţii terenului s-a utilizat metoda grafică suedeză (Fellenius).