ACTA MONTANA 1992
Series A, No. 2(88), 193-200

# INDUCED SEISMICITY AT MIROVO SALT DEPOSIT, BULGARIA

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## Introduction

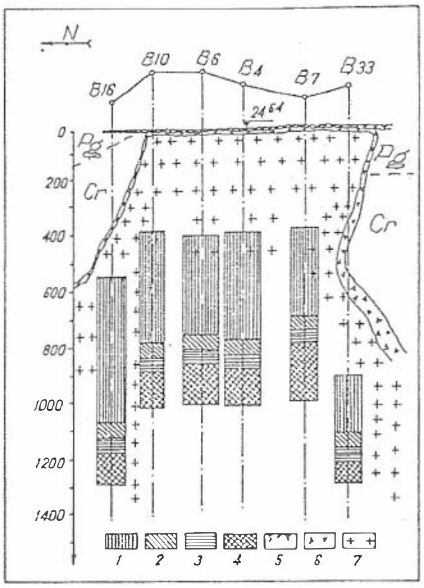
In the process of modern technologies development the social vulnerability increases because of human actions, directed in looking for new energy sources, communication systems and using of complex technological systems. These actions very often provoke induced seismicity, even in regions where seismic activity has not been observed in the past. Usually these are industrial zones where there is coal, salt or other deposit extraction processes or possible big soil mass collapse (dams, reservoirs, etc.) Similar example is the Provadia region, the only salt deposit in Bulgaria that is explored. The purpose of this study is to present some basic results of longterm observations of the dynamic processes in the region of the salt deposit.

## The salt deposit

The salt diapir is claimed to be unique geological feature, several kilometers across at its surface exposure, extendening and broadening to depths of perhaps 3500m.The shape of the diapir is a frustum of a cone. Its upper part is from 12-20 meters under the ground. In depth it reaches 3500m-fig.1. There is formed a salt layer in the range of depths 3500 -4500m. The deposit is imbeded in cretaceous limestones and dolomites and paleogene marlstones and it is covered by quaternery sediments. The mineral composition of the salt rock mass building the salt body is not homogenious and hallite is the predominated in this composition. The statistical analysis of the available information shows significant and irregular unhomogeneity of the rock salt massif. Rock salt physical and mechanical

Vertical cross sections of the salt diapir

1a - North-South direction



1b - East-West direction

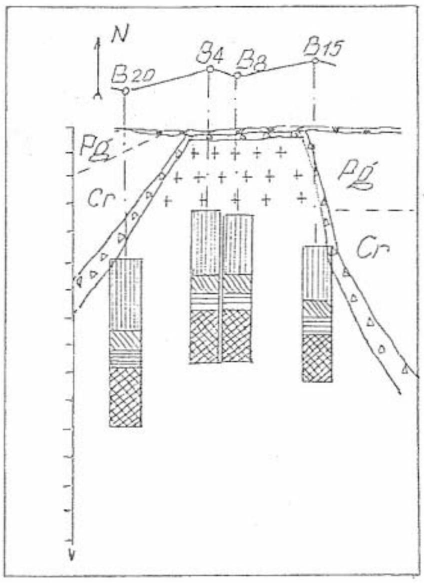
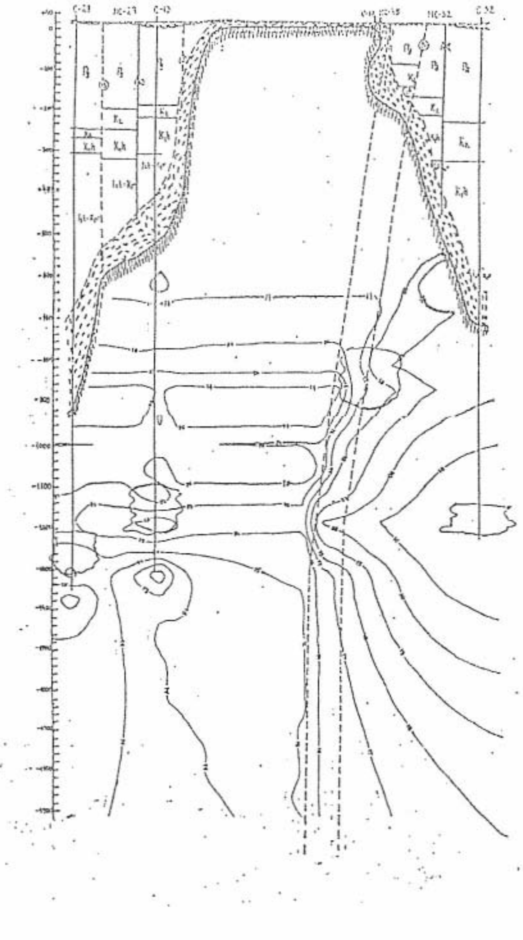


Figure 1

1 - 6 roof chamber level: 1-designed level, 2-1995 year, 3-1990 year, 4-1985 year; 5 - soil layer, 6 - breccia, 7 - rock salt.



Compressive strength distribution in depth

Figure 2

properties are determined using test cores from more than 30 boreholes at different depths. The average in-situ density is as follows: salt-2.17g/sm.cub, insoluble dirt -2.74g/sm. cub. and salt - marl rock - 2.23g/sm.cub. The strength parameters vary in a wide range. The basic one , the compressive strength is from 8.5 to 30MPa with average values Rc = 14 - 16MPa (lab test) and Rc mass = 5.4 - 5.8MPa (massif). The compressive strength trend analysis has shown significant variety in its distribution - fig.2. The rock mass rating according Bieniawski is in the range of 14 <= RMR <= 41 which determs the salt diapir as a weak or very weak massif. Salt- marl rock test cores have been tested under uniaxial and threeaxial compressive longterm loading (703 hours). Quite strong expressed rheological characteristics of the salt rock have been observed. In the case of loading, overcoming with 50 percents the compressive strength, the longterm strength is evaluated in the range of 5.2 to 5.4MPa and the observed creep velosity is quite high. The stress state of the indisturbed by the faults salt rock massif at different depths and of the allerolites and argillits of the underlaying formation is determined by five independent methods [5] using the so called 'rock memory'. The stress tensor variation in the salt diapir and the underlaying formation is shown on fig.3. Horisontal tectonical ground movements are registrated by geological and rock mechanics methods. These movements cause horizontal stresses overcoming with 50-60 percents the vertical geostatic stresses.

## Extraction technology description

The extraction technology has been worked out by VNIMI "GALYRGIA" - Saint Peterbutg, (Russia). The salt is extracted from above 1200m level by solution using a telescopic borehole system circulating water at a well head pressure of 50 bars. The roof shape is controlled by floating oil layer. The boreholes are situated in square net 200x200m. The shape of the chambers is controlled twece annually. Their diameter varies from 100 to 140m (the design diameter is 50m).

## Explotation regime parameters

The observations for the period from 1952 to 1992 show that the salt massif has become lighter with Pq=5.3*10exp6t dry material - approximately 1500000t per year - fig.4. The relationship between extracted salt mass and the subsidence

Stress tensor varuation
in the salt diapir at depths to 1000m - fig.3a, 1200-1700m -
fig.3b and underlaying formation - fig.3c

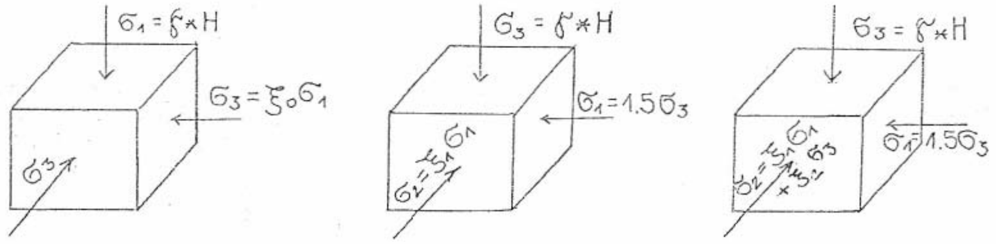



fig.3a fig.3b fig.3c

Figure 3

Relationship between extracted salt mass, time,
subsidence and earhquake occurance and intensity

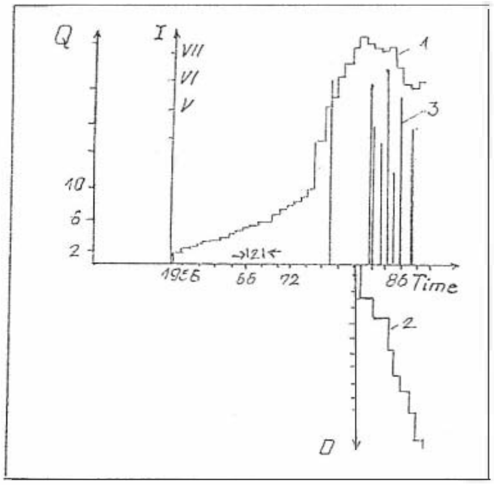



Figure 4

Q - quantity extracted salt mass in 10exp5 t (1),
D - subsidense of the area over chamber 6 in mm (2),
I - earthquake intensity MSK64 (3).

of the area over the chambers is shown on the same figure. The volume of the extracted salt quantity is 23.7*10exp7 m.cub. The extraction coefficient of the deposit as a whole is K=0.1. The brine weight in all chambers is Pr=31.88* 10exp6t. The total unloading Pt=Po-Pr, directly influencing the stress and strain redistribution in the massif and surrounding rocks and this way influencing the regional seismic activity is approximately Pt=30*10exp6t. Po is the chamber material weight before extraction.

Historical seismicity of the region

The Bulgarian territory is characterized by high seismic activity (the intensity map shows I=VII by MSK 64 for more than 65% of the territory). There are many differently orientated faults in the deposit region, forming complex tectonical points. On the potential seismic activity map is shown that near the salt deposit could occur earthquakes with magnitude M=5.6-6 at distance R=10km; M=5.1- 5.5 & r=1km and M=7.5-8 & R=55km. Synthetic accelerograms from this potential sources are generated - fig.5. Static and dynamic analysis is carried out using the FEM (finite element method) and these generated accelerograms.

Observation systems results

Two local observating systems are built in the deposit region - geodetical and seismic one. The geodetical observations have been processed on large and close net. A constant subsidence with average velocity 3 - 4.5sm per year and horizontal block movements have been observed in this region for the recent few years.

Seismic regime parameters

More than 40 components have been registrated and analyzed for the period of 10 years after the local seismic network building. The number of events N(M) with magnitude M in the range of 1.8 <= M <= 4.9, corrected for one year is lgN=1.90-0.68M. The epicentral distances vary from 6 to 27km. According to the potential seismic sources map the maximum expected magnitude is 5.6-6 for the area of radius r=10km around the site and reduced depth 5-10km. The main conclusion is is that these records are saturated with high frequency vibrations. The maximal periods are in the range of 0.085-0.2sec for the vertical components and 0.1- 0.57sec for the horizontal ones. Another special feature is the impacting events character and the low

Generated synthetic accelerograms
Figure 5a and 5b

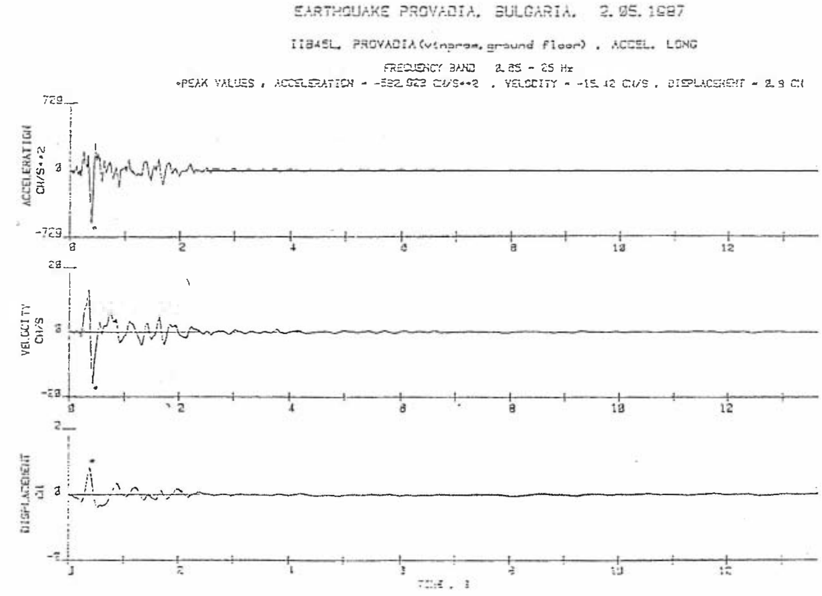
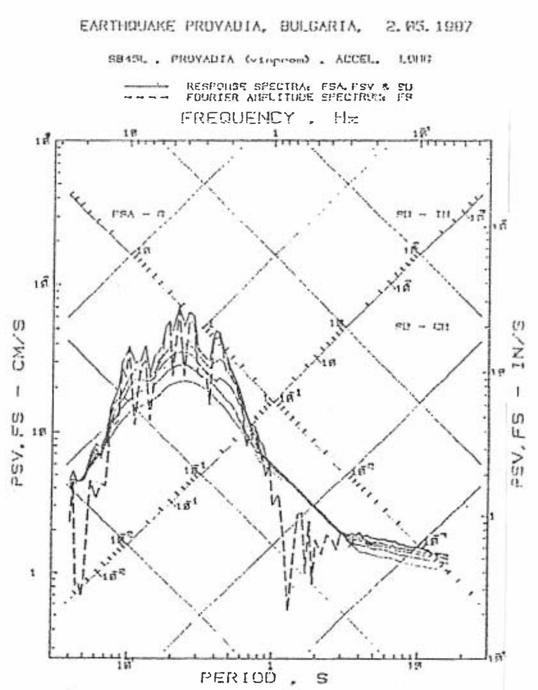



Figure 5a




Beniof graph

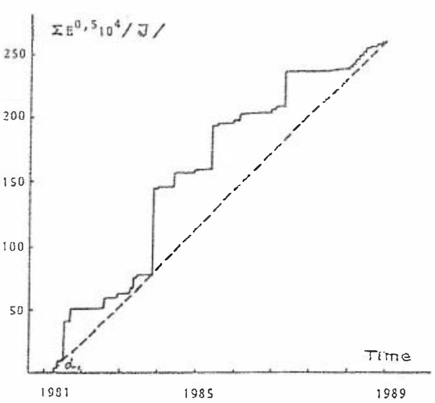



Figure 6

duration of the maximum acceleration part of the records 0.12-2.97sec. The values of the peak ground accelerations are quite high, they overcome 0.5g. The elastic strain release during earthquakes or ground deformations provoking such events can be characterized by Beniof method - fig.6. Energy, accumulated in the terrestrial medium can be expressed by the equation $E=0.5*v*e^2*V$, where v is the Poisson ratio, e is elastic strain and V is terrestrial medium volume, which elastic release causes earthquke. The strain release velocity is characterized by the gradient of the Beniof graph. Analyzing this graph we should have in mind that more accumulated strain energy corresponds to greater limit strength. In our case the gradient of the Beniof graph is 51deg which means that the limit massif strength is relatively low in the discussed area.

Conclusions

Analysis of the stress state field at different depths is processed. It is seen that new conditions of the geodynamical processes, seismic excitations and ground deformations have been created during the process of continious explotation of the salt deposit. At large depths, where strong ground motion energy is accumulated, the massif is in a state of unstable equilibruim. Salt extraction could be act as a starting device for energy release. On the other hand the analysis of the observed relationship between seismic activity and extracted salt mass from depths of 1000m shows that an increment of 200000t of the extraction mass can be a starting device for an erthquake occurance in the case of total extracted mass overcoming 2200000t. The adduced quantative decisions in our studies give us the reason to suggest that at depths above 1000m less quantity extracted salt could provoke earthquakes. We have to mention that the extracting technology changes could be developed in two main directions - 1) geometrical changes of pillars and chambers sizes and 2) reducing of the well head pressure, but not every change could be useful and quite efficient to reduce seismic activity of the region, having in mind the present region state. That is why we need to specify and improve all deposit observation systems and that way to realize a complex and objective approach for any technological or structural change establishment.

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