SEISMOMECHANICAL BEHAVIOUR OF THE MIROVO SALT DIAPIR (Bulgaria)

MIROVO TUZ OCAĞININ DEPREM DAVRANIŞI

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ABSTRACT

An estimation of the degree of influence of the salt mine dynamic behaviour on its safety exploitation is made. Three types of models: (1) a virgin massif - stage 1958, (2) a model - stage 1993 and (3) a model - expected stage the year of 2000 are analyzed. The acceleration distribution in depth is performed. Safety coefficients for all chambers of the chamber-pillars system are calculated. The presented results and conclusions can be used for some technological recommendations.

1. INTRODUCTION

In the recent years the world public has become increasingly alarmed by disasters as earthquakes - natural (tectonic) as well as man-made ones. The man-made (induced) earthquakes are primarily caused, or at least triggered, by the changes in the natural mechanical equilibrium in the region of intensive human activities such as mining. Unfortunately at the present stage of knowledge and technology it is not feasible yet to prevent the earthquakes and their disastrous consequences. But in the case of induced earthquakes man can exercise control in avoiding the damages by a proper planning of his activities and management of his environment. It is of great practical importance to have in mind this at the earliest stage of design. Risk assessment as well as all spectra of earthquakes engineering analysis are definitely important, i.e. predisaster activities intended to prevent catastrophes or at least to mitigate their disastrous ecological effects. In the context of this paper the general philosophy of investigations for analysis of the seismomechanical behaviour of the salt diapir is:

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- evaluation of tectonic, hydrological and macroseismic data;
- global analysis of the subsidence experience;
- study of factors influencing the global stability of the salt diapir.

The first and second investigations are discussed in other papers [5,6]. The main purpose of the present investigations is to estimate the degree of influence of the dynamic behaviour on the safety exploitation. The authors emphasize on the fact that the induced seismic activity is a dilemma to the engineers responsible for every project, because the vague uncertainty of induced earthquake risks contrasts with truly catastrophic consequences.

The discussed MIROVO salt deposit is the only terrestrial salt source in Bulgaria up to now. It is situated in an industrial area, 50km inland westwards of the town of Varna.

2. GEOLOGICAL DATA

The geological structures, tectonic situation and hydrological conditions of the region have been studied by many Bulgarian specialists [3,5,6]. The salt deposit itself is a diapir structure, extending and broadening to depths of perhaps 3 500m and a volume about 6 km^3. A horizontally deep seated salt layer is formed in the range at depths of 3 500 - 4 500 m. The deposit is imbeded in cretaceous limestones and dolomites and paleogene marlstones. It is covered by aluvial quaternary sediments. In the process of the salt-mass intrusion in the salt system a covering breccia has been formed. Hallite is predominant in this composition. About 1/3 of this rock mass is an insoluble component (marlstones, argellits, aleurolites, limestones and dolomites) irregularly situated. The investigations of the diapir are made in a set of 200x200m by boreholes.

The salt is being extracted from 1958 on three levels - 1000, 1200 and 1700m by leaching (330 gr/lit concentration of the solution) using a telescopic borehole system circulating water with a well head pressure of 50 bars. The chambers diameters vary in the range of 100-140 m and height up to 400 m. On the bottom 30 % of the well's volume is filled with marlstones. The physical and mechanical properties of the salt rock and the surrounding rocks are determined by core specimens from more than 30 boreholes. Two general types of geological mediums are distinguished - the first type is insoluble components IC $< 20\%$ and the second one has IC $> 20\%$. The average density is as follows: salt - 2.17 g/cm^3, insoluble components - 2.54g/cm^3, salt-marl rock - 2.23g/cm^3 and salt solution 1.23 g/cm^3.

The design procedure is performed by the"GALURGIA"Institute St. Petersburg taking into account the mean strength R_c=20MPa and the coefficient of longterm strength K=0.6 which should ensure a safety coefficient n=2.8-2,5 for the preventing pillars. The significant change of the compressive strength in depth is obvious. It varies from 23 to 9 MPa. The zones of the minimum R_c are at depths of 1600-1800m. For the dynamic analysis some regression relations among salt rock mechanical properties are used:

$$E_{dyn} = 3.5*E_s \quad (1)$$

$$E_s = 2.74*R_c - 0.766\,,\ r_{xy}= 0.916 \quad (2)$$

$$G_{dyn} = 3.52*R_c \quad (3)$$

where Edyn, Es - are modulus of elasticity, dynamic and static in MPa*10^2.

3. SEISMOMECHANICAL DATA

There is information about the strong earthquakes in the region of Provadia since the beginning of this century. In the period 1900-1903 four earthquakes with intensities five and assessed magnitude 2.6-3.8 are registered. In the period 1905-1975 there is no information on susceptible earthquakes [3]. The data of 1976-1993 show 14-15 earthquakes with a magnitude M>=3.0 [2].

About 81 components of accelerograms [5,6,7] registered by the local network of accelerographs SMA-1 for the period 1981-1993 are analyzed. The dynamic effect of the different records varies from 1.2-6.7. The ratio between the maximum horizontal acceleration and the vertical one is 0.17 - 2.26 for the local earthquakes. The predominance of the vertical components is evident for the 60% of the records. In 80% of the records the amplitudes of the horizontal components are between 20-160 cm/s^2. The analysis of the frequences content for the horizontal components is within the range 0.08-0.23 s and in the range 0.05-0.23 for the vertical components.

4. SITE RESPONSE ANALYSIS

The work presented here takes into consideration the potentially dangerous modifying effect that the salt extraction can have on earthquake motions as they propagate from the bedrock level to the ground surface. This fact has to be incorporated in the seismic analysis of pillars and the building of a new salt-factory. In model 3 it is assumed that the yearly extraction up to the year of 2000 will be 600 000 tons (as 1993). Another assumption concerning model 3 is that all the extraction will be concentrated at the level 1 700 m.

For the dynamic response two types of material behaviour have been accepted - linear and nonlinear hysteretic. To assess the fact that under cyclic loading (sesmic excitation) the stress-strain behaviour of the salt is hysteretic, a

Ramberg-Osgood model has been developed. For this purpose experimental investigations [1] have been used.

The hysteretic model calculates strains or deformations as an explicit function of stress or forces. The relationship is defined by two functions - one for loading (4) and one for unloading (4a) in the following form [1,4] :

$$D / D_c = F / F_c [1 + \alpha I F/F_c I (\beta\text{-}1)] \quad (4)$$

$$(D\text{-}D_o) / 2D_c = (F\text{-}F_o) / 2F_c [1 + \alpha I(F\text{-}F_o)/ 2F_c I(b\text{-}1)] \quad (4a)$$

where

F and D - current force and deformation,

F_c and D_c - control force and deformation,

F_o and D_o - force and deformation at current unloading point,

α and β - control parameters.

The shear modulus G_{max} at low strains is calculated from relationship [3] and the trend analysis. The basic approach to determine the parameters α and β requires knowledge of the force-deformation relationship of the salt under cyclic loading. Because of lack of experimental data about the cyclic test of the salt in the condition of extracted massif only the virgin model analysis was carried out.

5. DISCUSSION OF THE RESULTS

In the present investigation a trend analysis for the compressive strength in two directions - horizontal and vertical is used fig.1. On fig.2 the eigenproblem solution is shown. The inverse iteration with Gram-Schmidt ortogonalization is implemented. The execution using three possible situations shows that the extraction does not influence the modes shape, i.e. the shear behaviour is kept. The visible changes depending on the extraction show mainly the second mode. The difference between the virgin model and stage 1993 in depth is about 16%. There are no considerable changes in the mode shapes between stage 1993 and 2000.

On fig.3 the distribution of the accelerations and displacements in depth normalized to the virgin model for the elastic behaviour of the materials is shown. The extraction has increased accelerations 60% and displacements 20% mainly in the depths of the highest chambers.

The trend analysis of the peak ground accelerations (PGA) and peak ground displacements in depth using the linear model versus accelerations and displacements for the hysteretic model only for the virgin massif is given on fig.4. An increasing of the amplitudes for the accelerations more than two times comparing the linear and nonlinear virgin model is observed. The correlation obtained by the nonlinear analysis is quite similar to the one obtained using the linear model. This is because the nonlinear properties were selected to reflect nearly linear response. In the case of sufficiently experimental data the

Ramberg-Osgood parameters have to be obtained to fit better the measured data. However, this adjustment was not pursued.

A spectral analysis for the surface and on level 1200m is carried out. The comparison between the response spectrum for the model 1993 versus the virgin model on the surface (fig.5) shows an increasing of the spectral amplitude in the range of periods 0.30-0.40 sec more than 70%. It is very dangerous for the structures with dynamic characteristics in this range. This situation is different at depth 1200m (fig.6). The increasing is less than 40% in the range of 0.1-0.2sec and 1.0-1.50sec. The safety coefficients (fig.7) determined through through the static analysis for all chambers are assessed. Some pillars at the depths lower than 1200m are close to the critical state. These results might be used for some recommendations concerning the exploitation process.

6. CONCLUSIONS

Three types of models for Mirovo deposit have been used: 1)a virgin massif (stage 1958 before starting the salt extraction); 2)a model with the size of chambers corresponding to 1993, and 3)a model with an expected size of chambers corresponding to the year of 2000.

The site response analysis is performed. The influence of the dynamic properties of the salt extraction on the dynamic behaviour is carried out.

Using the results of the present investigations and static analysis the safety coefficents are assessed for all chambers.

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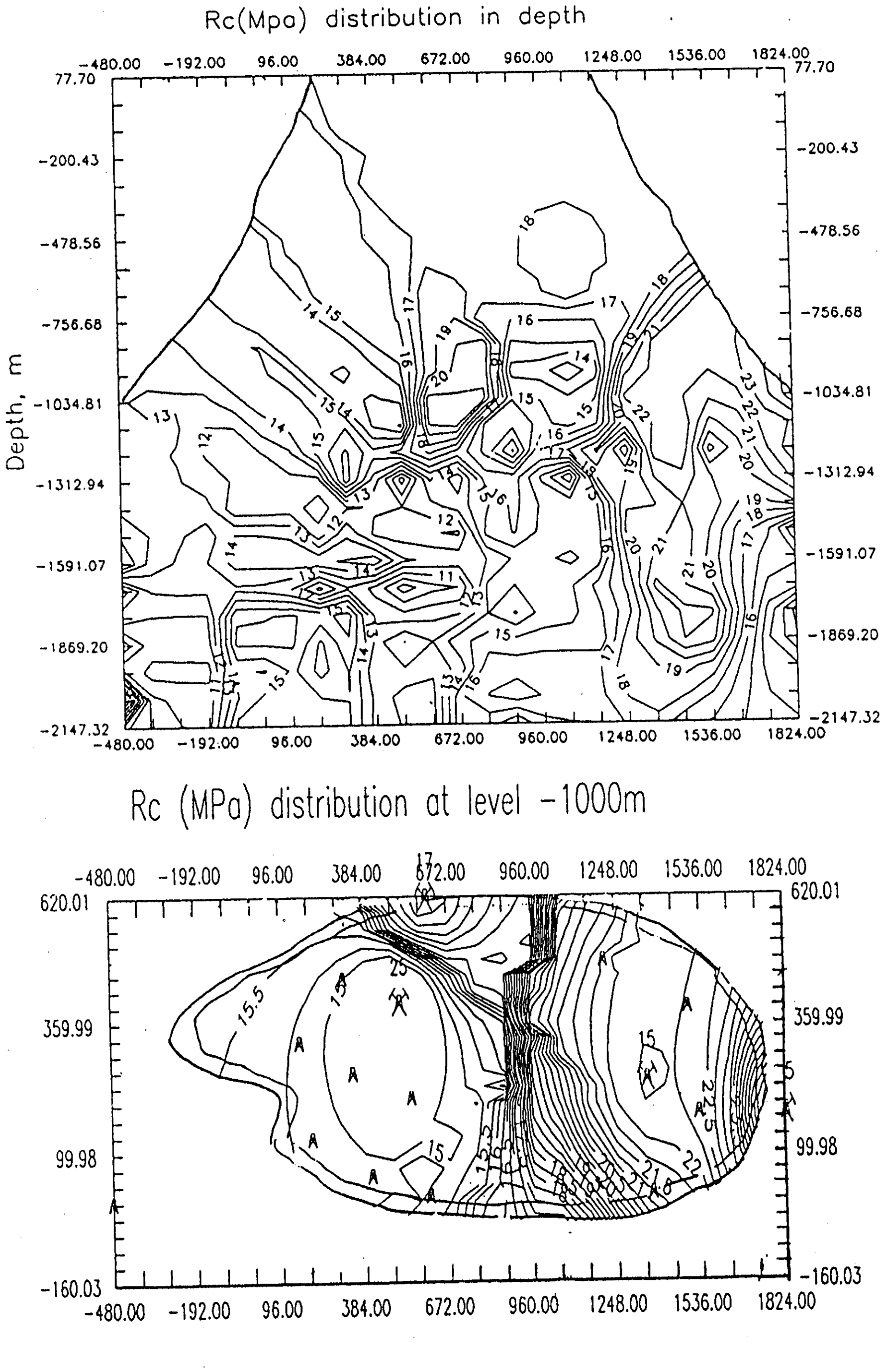
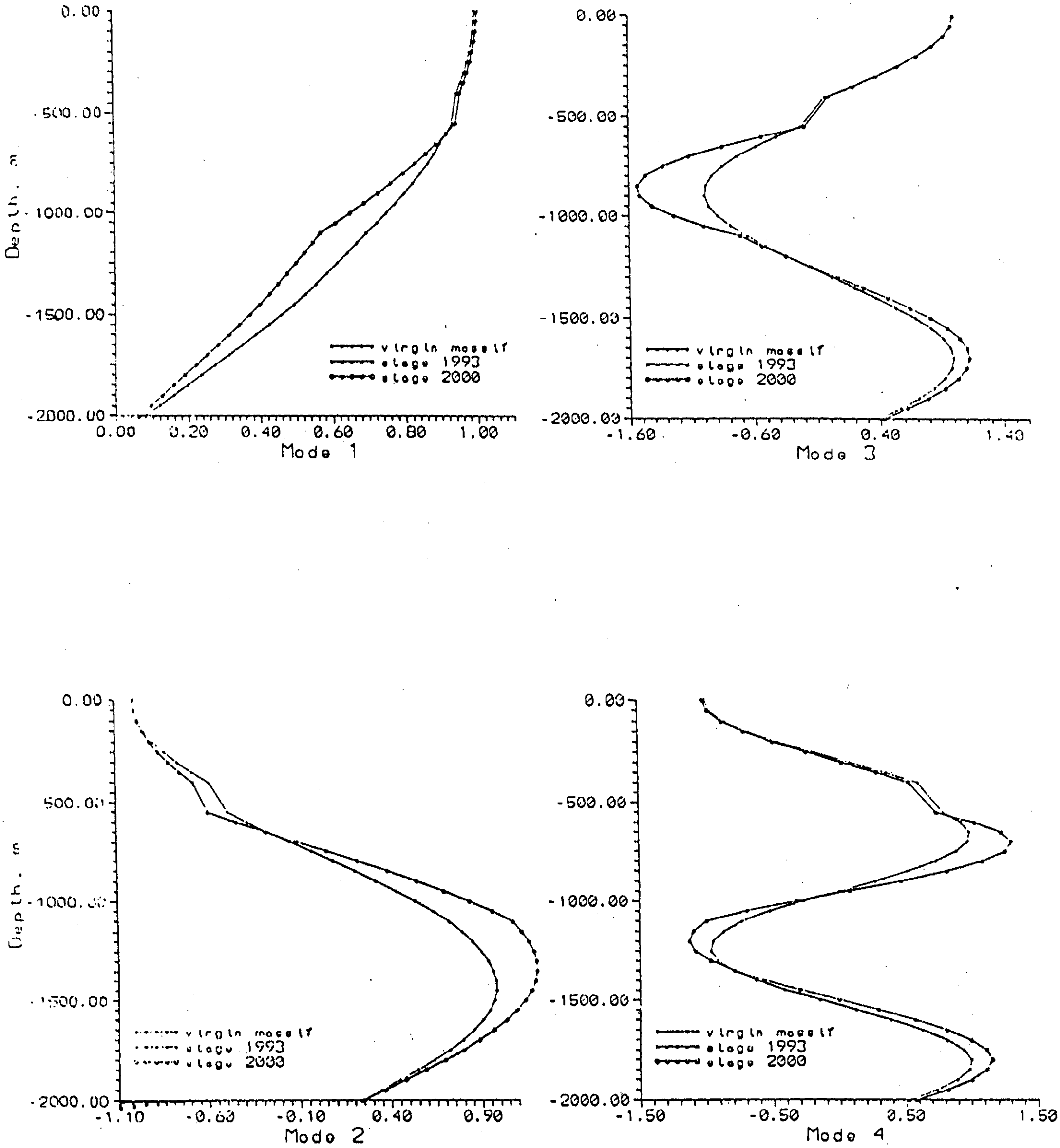

Rc(Mpa) distribution in depth
Depth, m
-480.00 -192.00 96.00 384.00 672.00 960.00 1248.00 1536.00 1824.00
77.70
-200.43
-478.56
-756.68
-1034.81
-1312.94
-1591.07
-1869.20
-2147.32
Rc (MPa) distribution at level -1000m
620.01
359.99
99.98
-160.03

Fig. 1



0.00
-500.00
-1000.00
-1500.00
-2000.00
Depth, m
0.00 0.20 0.40 0.60 0.80 1.00
Mode 1
virgin massif
stage 1993
stage 2000
-1.60 -0.60 0.40 1.40
Mode 3
-1.10 -0.60 -0.10 0.40 0.90
Mode 2
-1.50 -0.50 0.50 1.50
Mode 4

Fig. 2

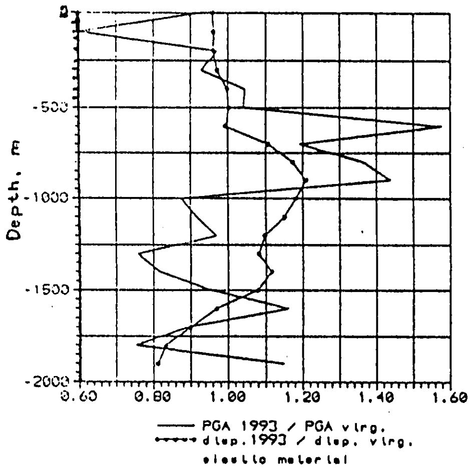


Fig. 3

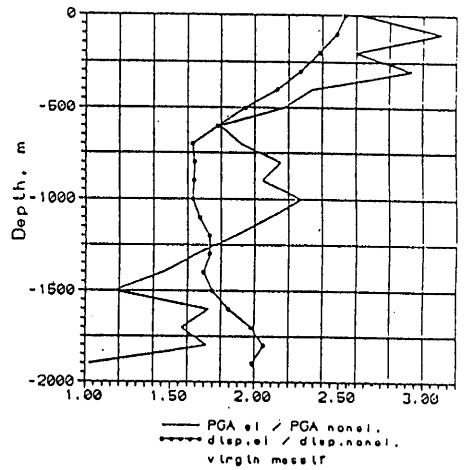


Fig. 4

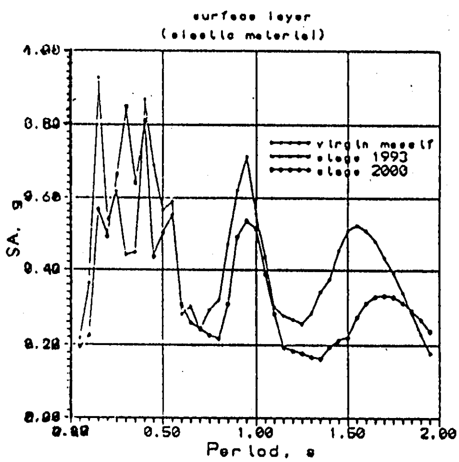


Fig. 5

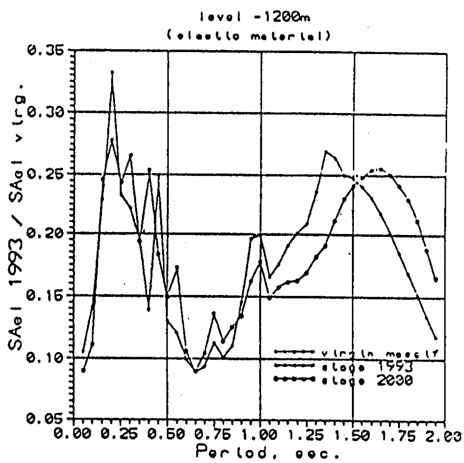


Fig. 6

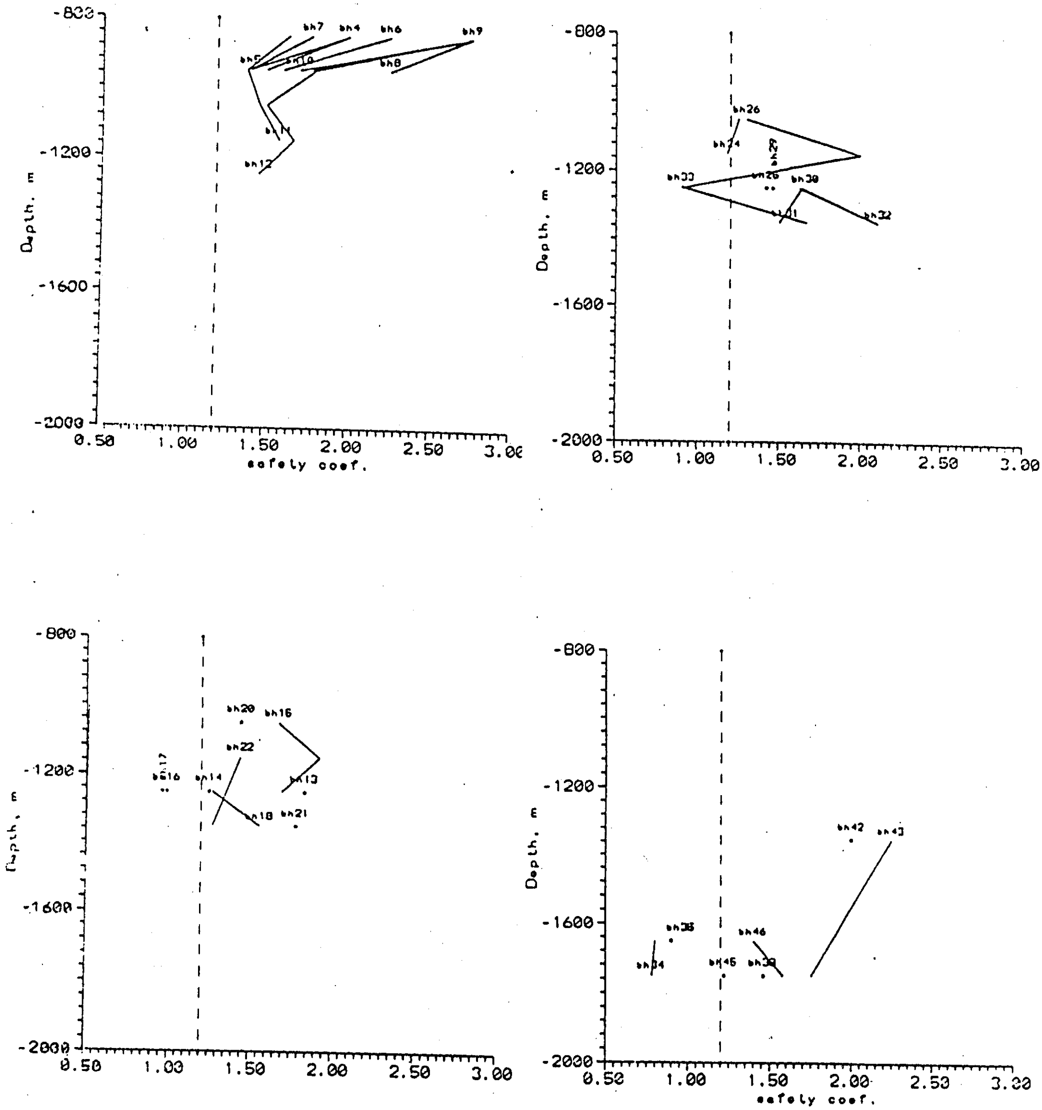

-800
-1200
-1600
-2000
Depth, m
0.50
1.00
1.50
2.00
2.50
3.00
safety coef.
bh7
bh4
bh6
bh9
bh8
bh10
bh12
bh26
bh24
bh33
bh30
bh32
bh20
bh16
bh22
bh14
bh18
bh21
bh13
bh42
bh43
bh46
bh45
bh34

Fig. 7