J. Earth & Space Physics. Vol. 30, No. 1 (2004) P. 11-14

Microgravity investigations of foundation conditions

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(Received:4 Feb.2003, Accepted: 6 Jul. 2004)

Abstract

A microgravity investigation was conducted on an excavated foundation located in the Technical University of Tehran. The aim was the detection of subsurface cavities or other anomalous conditions that threaten the stability of the foundation. The survey consists of 420 gravity stations. The positive coarse grain alluvium saturated by surplus water and negative cavity anomalies have been detected based on the Bouguer and second vertical derivative maps. The depth of the sources have also been determined. To confirm the results an inversion 2D-modelling is also applied to residual anomalies. Some of the shallow accessible anomalies have been confirmed in the field by excavation.

Key words: Microgravity, Anomaly detection, Depth estimation

1 INTRODUCTION

Delineation of subsurface anomalies, such as cavities, is one of the most frequently cited applications of microgravity. Cavities have been the most common targets, detected by microgravity whereas cavities present a very difficult objective for other geophysical methods (Franklin et al. 1980, Butler, 1977). The cavities could be natural, such as solution cavities in limestone, dolomites and evaporates or man-made, such as tunnels or mines and may be air-filled, water-filled with some secondary geologic material. Butler (1984), presented a pioneer job in detecting the shallow surface cavities and tunnels which have a vital role stability of the foundations and concluding that microgravity is the most promising surface method when shallow negative and positive anomalies are targeted.

2 SITE GEOLOGY

The site is located in the Technological University of Tehran. The main stratigraphic section is called Kahrizak formation (Tehrani, 1988) which is formed form horizontal layers of alluvium with loose cement and a low compactness and different size of grains. The thickness of this formation has a wide range between 5 to 40 meters. This formation is covered by present alluvium which is produced by eroding and depositing of Kahrizak formation.

3 FIELD PROCEDURES

The gravity grid consists of 420 measurement points over an area with dimensions 48×38 meters with the average coordinates, 35.74 degree of north latitude and 51. 39 degree of east longitude.The foundition is about 10 meters lower than ground surface. A basic grid dimension of 2 meters was used. Data were collected with a CG3-M gravity meter with a sensitivity of approximately 1μGal.

4 GRAVITY CORRECTION

Measured values are corrected for effects caused by variation in latitude, elevation, topography, earth tides and instrument drift. Long-term drifts of the gravimeter are removed using a base station close to the site (at institute of geophysics). Short-term drifts have also been removed by several base stations in the site. For latitude correction the equation (Yule et al, 1998),

$$\delta g_{zl} = \pm\ 0.811 \times \sin(2\phi) \times \Delta z, \qquad (1)$$

is used, where δg_{zl} is given in μGal, Δz is the north-south distance (in meters) between the measurement point and the base station, and φ is the reference latitude of the base station. Free-air and Bouguer corrections are computed through the following equation.

$$\delta_{gF+B} = (0.3086 - 0.0419d)h, \qquad (2)$$

where d is the average density which has been defined by prior information equal to 1.78 gr/cm^3, h is the height of the measurement points and δ_{gF+B} is the correction in mGal. As the site is located farther than 20 meters from any building, the terrain correction has been done for each point by approximating the average height in a cap with 20 meters radius around the point and using the Hammer table. Considering these corrections Bouguer gravity anomalies are,

$$\Delta gB = (g_{obs} \pm \delta_{gzl} + \delta_{gF+B}\delta_{gt}) - \gamma, \qquad (3)$$

where g_{obs} is the observed gravity, δ_{gt} is terrain correction and γ is normal gravity.

5 INTERPRETATION

Using equation. 3 the Bouguer anomalies are computed and shown in figure. 1. The positive (coarse alluvium saturated by surplus water) and negative (cavities or tunnels) anomalies are quite demonstrated quite well on the figure. To interpret the anomalies, Geosoft (version 5.1.5) is used. To confirm the shallow anomalies which are vital to the condition of the foundation, the second vertical of the anomalies are computed through Fourier transform method (Figure. 2)

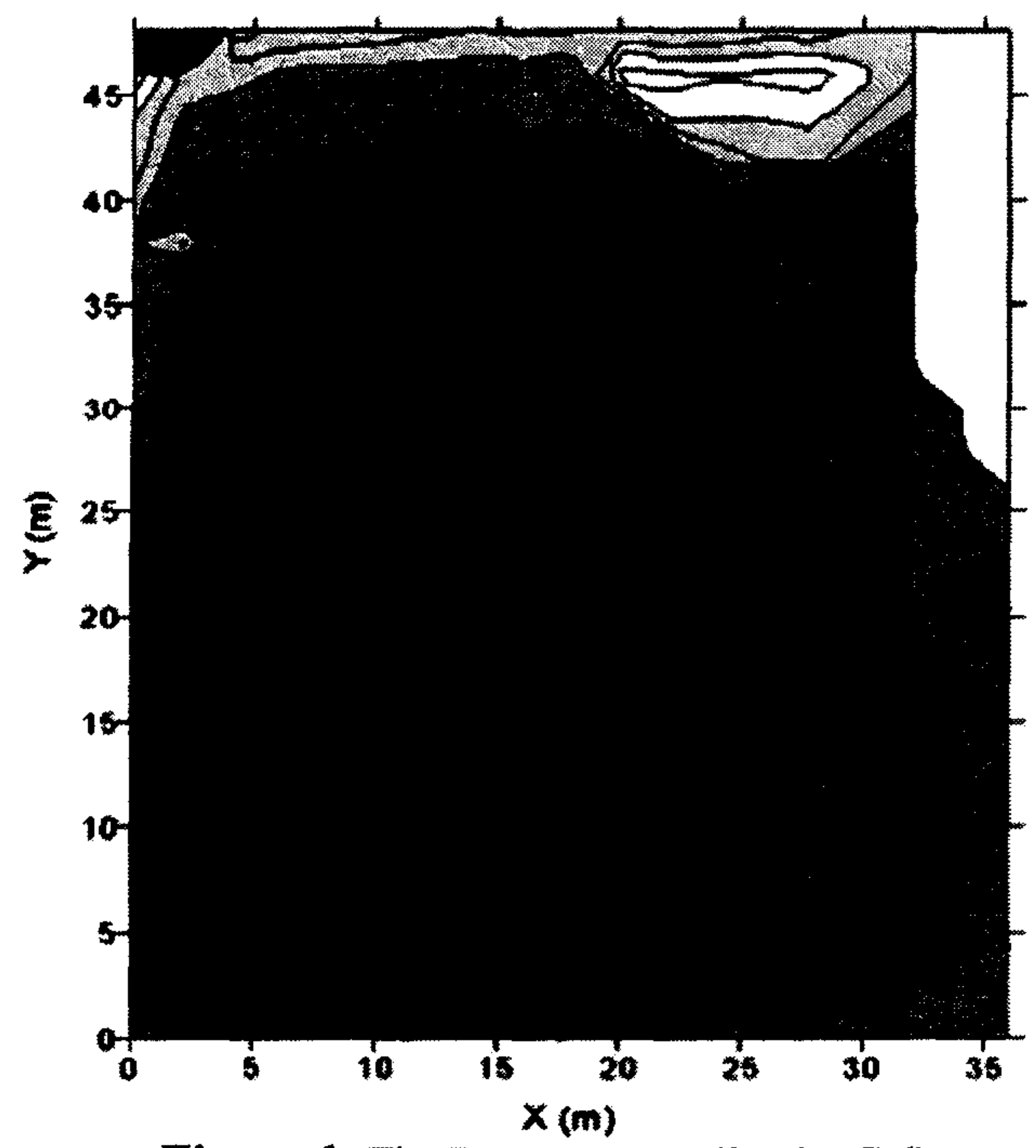

Figure 1. The Bouguer aomalies (mGal).

$$\frac{\partial^2 g}{\partial z^2} = \frac{1}{4\pi^2} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} F_0(p,q)(p^2+q^2) \exp \left[i(px+qy)\right] dp dq \quad (4)$$

where $F_0(p,q)$ is the Fourier transform of the data $g_0(x,y)$which is the Bouguer or residual anomaly at the ground surface. Determining the coordinates of the anomalies, Euler deconvolution method.

$$(x-x_0)\frac{\partial f}{\partial x} + (y-y_0)\frac{\partial f}{\partial y} + (z-z_0)\frac{\partial f}{\partial z} = Nf, \quad (5)$$

where x_o, y_o, z_o are the coordinates of the point source and N is structural index and f is the first vertical derivative of gravity anomalies, is applied (Figure. 3). Inspecting the Figures five anomalies are distinguishable and marked on figure 2.

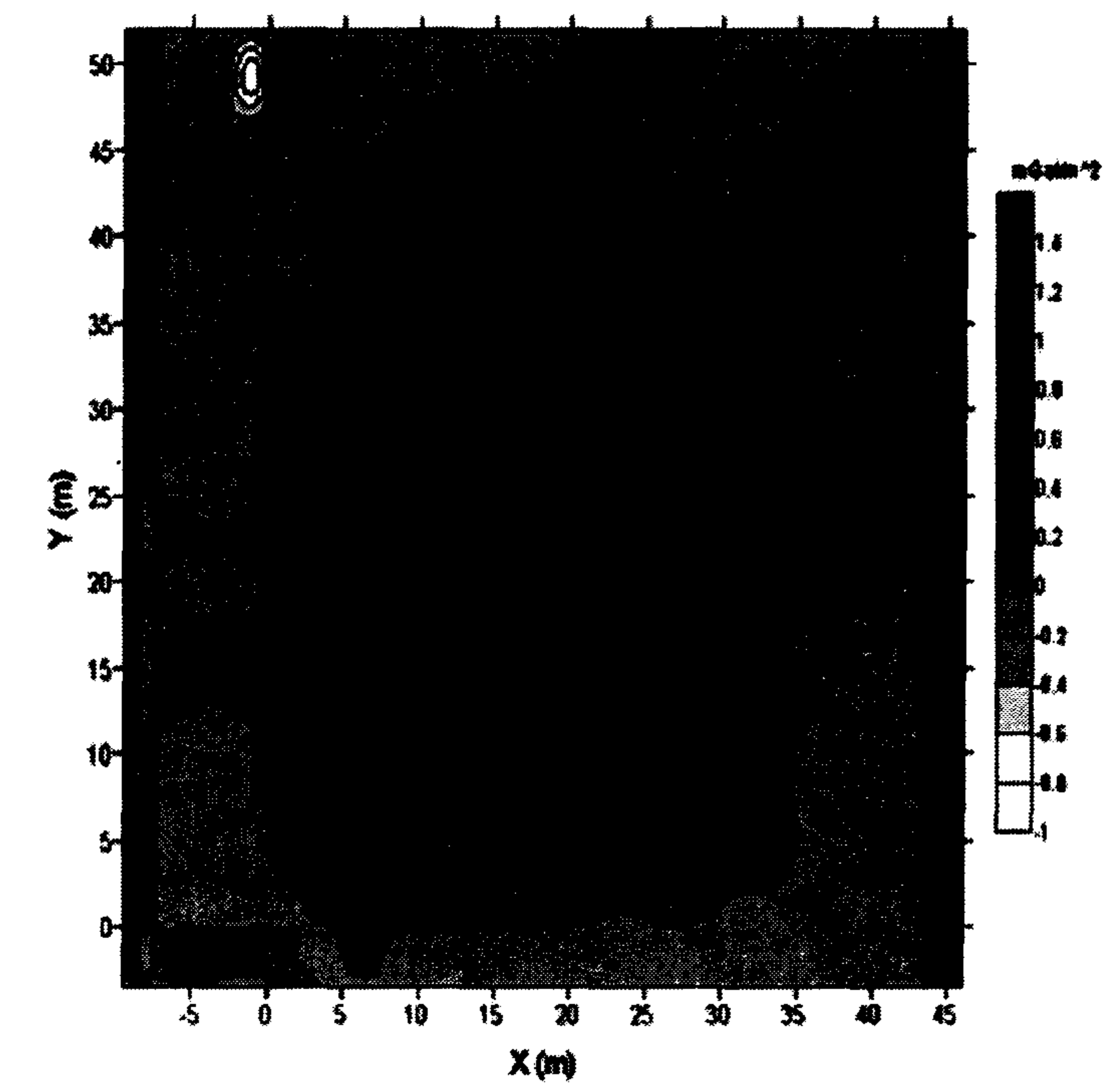

Figure 2. The second vertical derivatives ($mGal/m^2$).

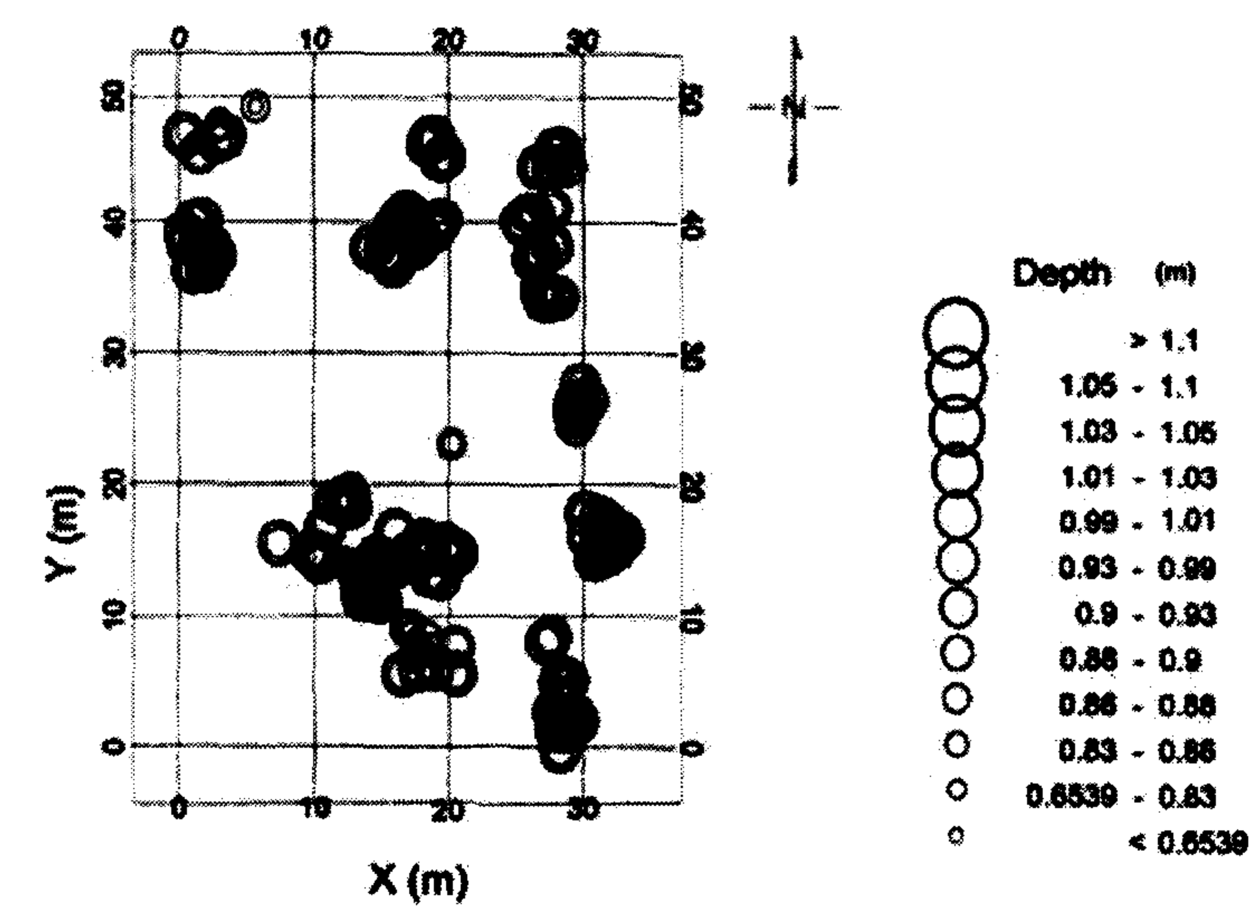

Figure 3. The radios of the circles represent the depth of the anomalies (m).

1- Negative anomalies belong to the lower-most part of the ramp which belongs to the excavated ground and handled soil with a maximum depth of 2 meters.
2. The positive anomaly outline a part of old surplus well which is filled with very coarse alluviums. The maximum depth of the anomaly is 2 meters. The existence of this anomaly is immediately approved by excavating the site.
3. The positive anomaly outline again the same condition of number (2) and approved by excavating the site.
4. The Positive anomalies at the north-west of the site which partly is under the side wall and can not be investigated at present. The maximum depth is about 2 meters.
5. The negative anomaly outline subsurface cavity with the maximum depth equal to 2 meters. To continue the interpretation process, the residual

anomalies are computed through estimating the difference between the observation and the trend. The trend values are computed by polynomial fitting.

$$T(x_i, y_i) = \sum_{q=0}^{t} \sum_{p=0}^{s} l_{pq} x_i^p y_i^q \quad (6)$$

where T (x_i, y_i) are the estimated trend values at the measurement points, (x_i, y_i), t and s are the order of the polynomial, l_{pq} is the coefficient of the polynomial and i=1, 2..., n; n = number of data points. The residual anomalies are presented in Figure. 4. To confirm the results an inversion modeling is applied for the most important anomaly (2). The modelling can be done quite easily due to the prior information obtained. The method expressed by Meju (1994) is used to compute the contrast density of the source. When a good prior information is available, this method can be used readily. The gravitational attraction of an n-sided polygon is firstly to be calculated (Grant and West, 1967).

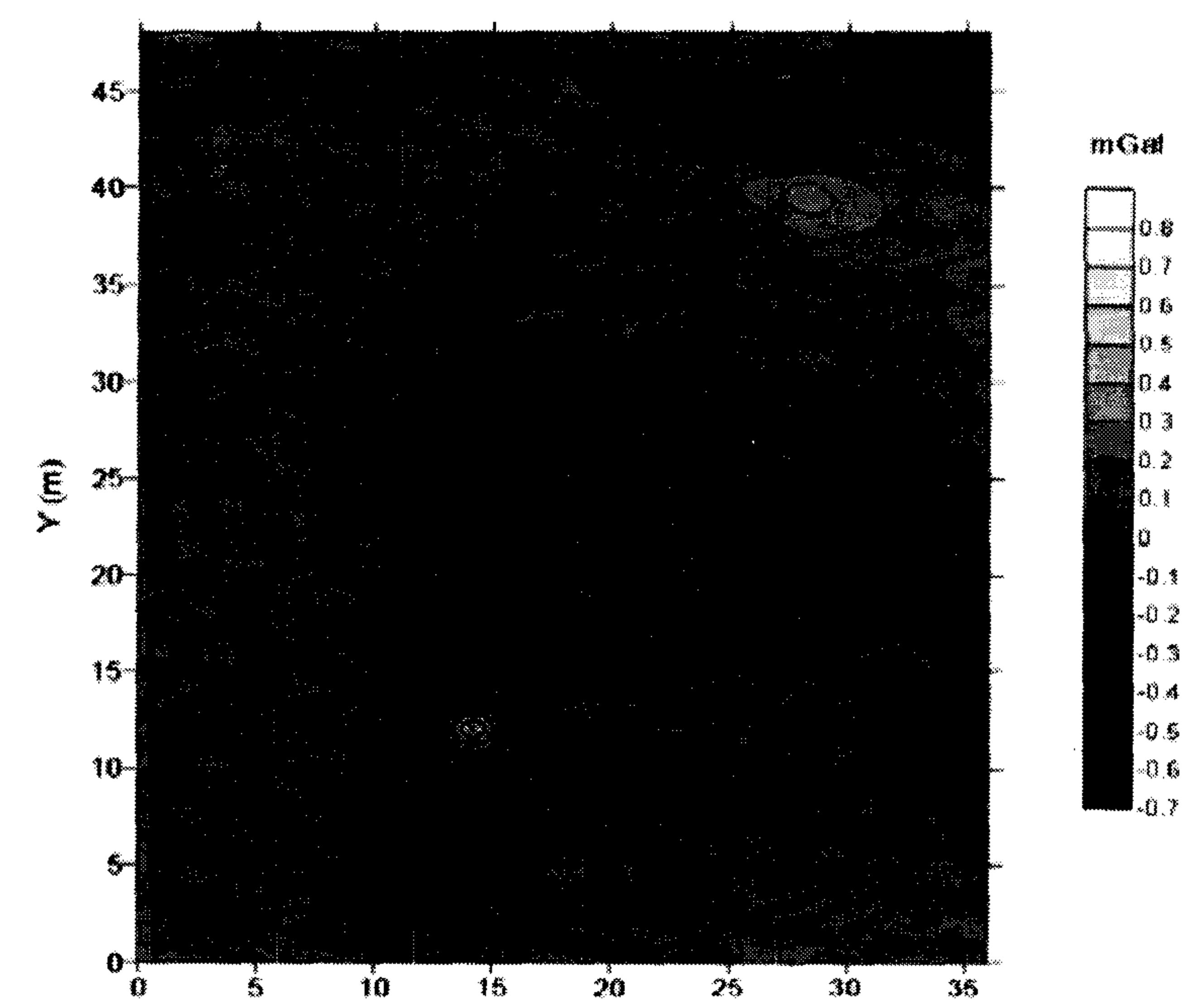

Figure 4. The residual anomalies (mGal).

$$g = 2G\Delta\rho \sum_{k=1}^{nsides} \left\{ \frac{b_k}{\left(1+a_k^2\right)} \right\} \left\{ \frac{1}{2} in \left(\frac{x_{k+1}^2 + z_{k+1}^2}{x_k^2 + z_k^2} \right) \right\} + a_k$$

$$\left\{ \tan^{-1}\left(\frac{x_{k+1}}{z_{k+1}}\right) - \tan^{-1}\left(\frac{x_k}{z_k}\right) \right\} \quad (7)$$

where $a_k = (x_{k+1} - x_k)/(z_{k+1} - z_k)$, $b_k = (x_k z_{k+1} - x_{k+1} z_k)/(z_{k+1} - z_k)$, G is the universal gravitational constant, and Δρ is the contrast density of the body with the surrounding medium. Then using the GRAVINV code the best contrast density for the assumed figure of the polygon which gives the best fit between the observed gravity and calculated data, is obtained. Figure. 5 shows the results for the anomaly (2). As it can be seen from this figure the width and the length of the anomaly are about 1.5 and 2 meters than the previous results.

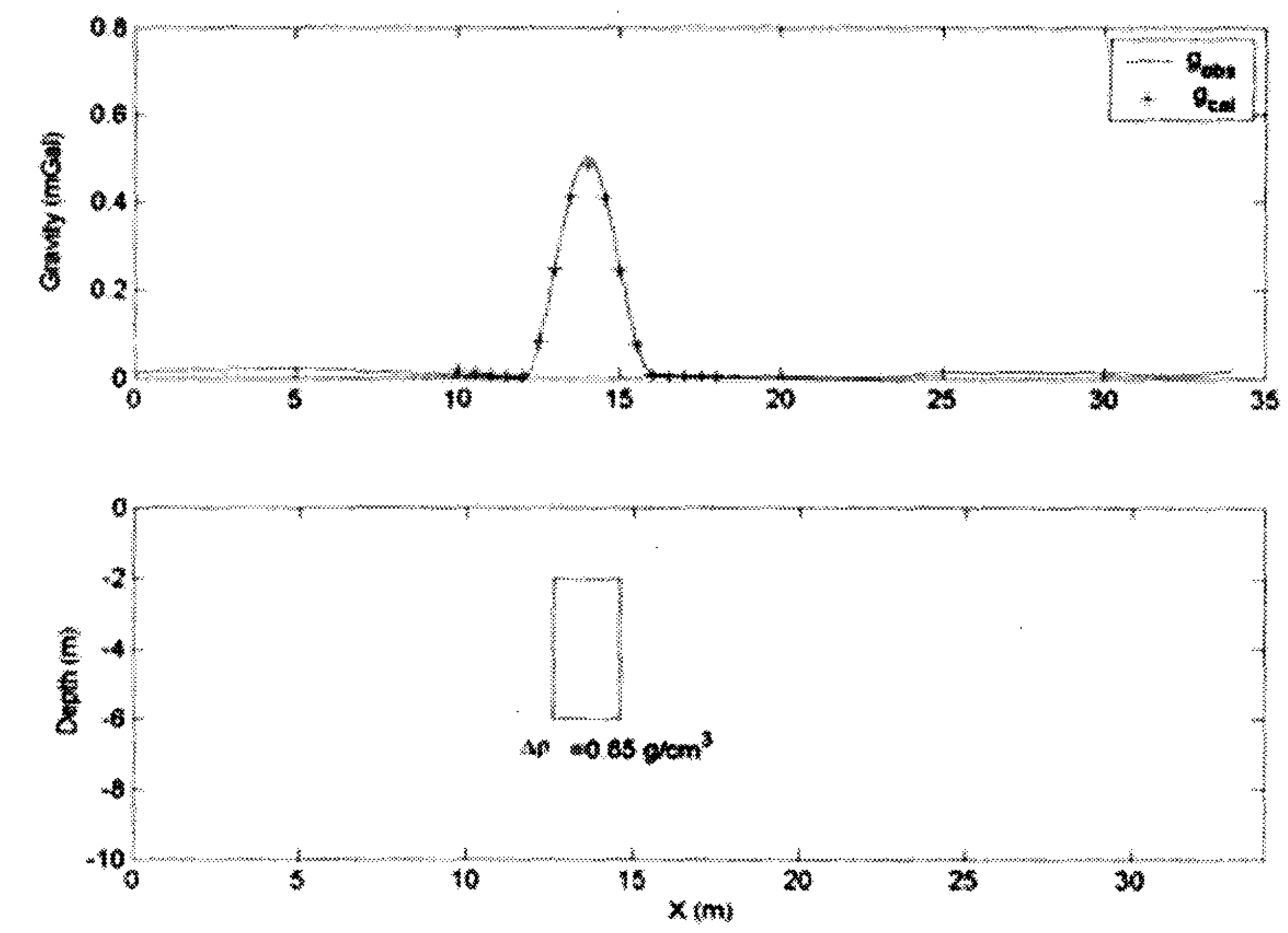

Figure 5. The modeling of anomaly (2).

6. CONCLUSION

Microgravity is an effective method to detect not only the shallow cavities but also relative positive anomalies which can be vital in geotechnical investigation of foundation. Quantitative parameters, exact coordinates and maximum depth of the sources, provide engineers with valuable information about subsurface shallow anomalies which could produce instabilities in the foundation subsequently constructed.

ACKNOWLEDGEMENTS

The author is thankful to the head of the Petroleum institute of Tehran university , Dr. Farhang Galali Farahani and the University of Tehran for all supports. The author is also thankful to Ing. Vahab Sharbaf Shoar for his assistance in field measurements.

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