Bitlis Eren Üniversitesi Fen Bilimleri Dergisi
BİTLİS EREN UNIVERSITY JOURNAL OF SCIENCE
ISSN: 2147-3129/e-ISSN: 2147-3188
VOLUME: 12 NO: 2 PAGE: 578-590 YEAR: 2023
DOI:10.17798/bitlisfen.1295828

Estimating The Location of a Buried Body from Magnetic Anomaly Through Normalized Full Gradient: A Case Study from The Sapinuwa Ancient City, Turkey

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Keywords: Geophysics, Normalized Full Gradient, NFG, Magnetic anomaly, Sapinuwa ancient city.

Abstract
In geophysics, magnetic data can be used to obtain information about the depth and location of the structure, whether it is near the surface or deeper. This study is an example of applying the Normalized Full Gradient (NFG) method to an archeological site to determine the depth and location of structures that cause magnetic anomalies at the archeological site. One of the parameters that affects the shape and size of the magnetic anomaly is the depth of the source causing the anomaly. For this reason, it is important to correctly determine the location of the source. One of the methods of determining the depth of the structure using magnetic field data is the NFG technique. When using the downward analytical continuation, bias occurs due to the transition of the depth of mass, which is invalidated by this method. The NFG technique has been tested on anomalies caused by prismatic synthetic models. Test studies with synthetic models using the NFG technique have yielded satisfactory results. Based on these results, the NFG technique was applied to the real magnetic anomaly collected from the ancient city of Sapinuwa. The results were compared with the building remains found during the proposed excavations. The results obtained were satisfactory..

1. Introduction

Potential field data has a wide place among various methods in applied geophysics. This stage is the result of the long-term development of applied geophysics. It has been applied to a significant extent, especially in oil and gas reserves and mineral explorations. Since the 1960s, thanks to the important developments in computer techniques, many successful applications have been realized in potential areas with the development of existing evaluation theories for the solution of geophysical problems.

It is a fact that geophysical methods are used extensively in hydrocarbon and mineral explorations, which are accepted as natural riches in many parts of the world until today. In recent years, it has been used intensively in the examination of the properties of structures very close to the surface or just below the surface, as well as in deep welded structures.

The aim of this study is to reveal the geophysical properties of such areas by using geophysical methods in archaeological areas. For this reason, the magnetic method, which is included in the group of potential field methods within the geophysical research methods, was used.

In this study, one of the geophysical evaluation methods, the NFG technique, which is based on the downward analytical continuation of the gradient field, was used. It is a method in which the relationship between the potential field and the source that creates the field can be re-established (for example, the analytic continuation method). This is the conversion of the measured magnetic field to the magnetic field in another, more understandable plane.

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Received: 11.05.2023, Accepted: 22.06.2023

Such a process is based on a very simple relationship between the determined singular points of the structures constituting the anomaly and the geometric shape of the structures (center of gravity, vertices of the polygonal section).

The analytical continuation distinguishes some indistinguishable structural anomalies in the observed magnetic field. Analytical properties are lost at singular points of the boundaries of the mass, leading to an anomaly in its magnetic potentials and derivatives. The shape of the source and the location of the source causing the anomaly can be determined from the knowledge of the source and the singular points at its boundaries. The downward analytical continuation values of the observed magnetic field data show irregular changes during the passage of the source causing the anomaly. The normalized Full Gradient method is one of the most successful methods used in the determination of the singular points of the potential fields. These methods are often called singular points method and were first introduced by Strakhov (1962) and Golizdra (1962) [1,2].

The NFG technique has been rapidly adopted since the 1960s, and this method has been used by researchers. In particular, it can be applied to identify singular points of potential areas [3-14]. In addition, this technique has been successfully applied to seismic methods [15] and electromagnetic methods [16]. Magnetic and gravity have been often used to model subsurface geology. The magnetic survey is widely used to estimate the geometric parameters of simple models. These models can be in the form of a sphere, cylinder, dyke, or thin plate [17-20].

Magnetic imaging (especially gradiometer), ground-penetrating radar (GPR), and Electrical resistivity tomography (ERT) methods have widespread usage in archaeological sites. In the past years, some of the applications of these methods are presented by Ekinci and Kaya (2006)[21], Balkaya et al. (2012)[22], and Büyüksaraç et al. (2014)[23]. In addition, in particular, some examples of archaeo-geophysical studies in ancient cities of Anatolia are given as Amorium [24], Baris [25], Commagene [26], Dedemezarı Nekropolü [27, 28], Kılıç[29], Malos [30,31], Parion, [32, 33], Pisidia Antioch [34], Side [35], Satala [36], Sardis [37], Smyrna Höyük [38, 39], Tepecik and Norşun [40], Zeugma [41]. In this study, the NFG technique was performed using field datasets containing magnetic profile anomalies caused by buried structures in the ancient city of Sapinuwa (Çorum, Turkey) and noiseless synthetically produced data.

2. Sapinuwa Ancient City

The ancient city of Sapinuva is an ancient city dating back to the Bronze Age, located in the Ortaköy district of Çorum province. It is known as the second-largest city of the Hittite kingdom. The city, which had great strategic importance, was also important politically and economically. Our study area is located in the north of Central Anatolia, 55 km southeast of Çorum city center, and 60 km northeast of Boğazköy in Ortaköy District. Today's Ortaköy District, with the Alan Mountains in the south and Karadağlar in the north, is on a plateau formed by terraces descending from west to east in the valley where Özderesi, a branch of the Çekerek River, is located.

The Hittite city of Sapinuwa is located about 3 km southwest of the Ortaköy District center, and appears as a widespread settlement on this plateau extending as terraces on the northern slopes of the Özderesi Valley, a branch of the Çekerek River. The city covers an area of 3 km in the east-west direction and 2.5 km in the south-north direction, including the lower and upper city (Figure 1).

Boğazköy was the most important center where the Hittites ruled in Anatolia. In addition, centers such as Maşat mound, Kültepe, Alaca mound and Sapinuva also have an important place. In Sapinuwa, there are large religious and administrative structures that also served as administrative centers from time to time. Due to its location, it has an extremely important strategic position. The city is located at a key point on an important passage connecting Göynücek-Amasya Plain to its east and Kelkit Valley, which is its continuation, to Alaca-Sungurlu Plains to its west and Boğazköy located here.

The city is located at a key point on an important passage connecting Göynücek-Amasya Plain to its east and Kelkit Valley, which is its continuation, to Alaca-Sungurlu Plains to its west and Boğazköy located here. There is a 20 km long corridor in which the Çekerek River flows, extending to the Göynücek Plain in the east of the city. On this corridor, front defense facilities were built by selecting key points. It is accepted that the city has adopted a highly effective defense strategy by using these front defense facilities.

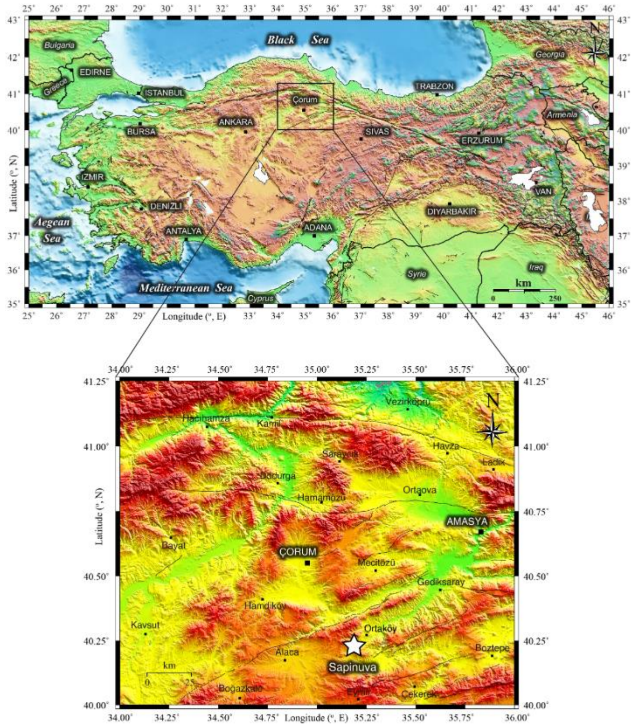

Figure 1. Location map of Sapinuwa ancient city. The map was generated using Generic Mapping Tools (GMT) [42].

3. Material and Method

3.1. Definition of the Magnetic Anomaly

Figure 2 shows the prism model. The vertical and horizontal magnetic field components are defined in [43] with equations (1) and (2), respectively.

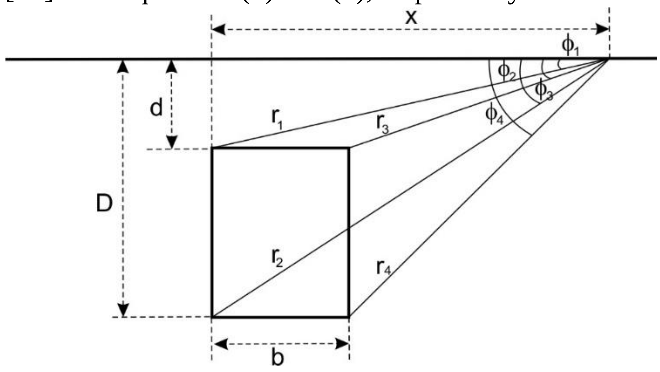

Figure 2. Vertical prism model

$$Z = 2k\left\{H_o \sin\beta \, ln\left(\frac{r_2 r_3}{r_1 r_4}\right) - Z_o(\emptyset_1 - \emptyset_2 - \emptyset_3 + \emptyset_4)\right\} \quad (1)$$

and

$$H = 2k\left\{Z_o ln\left(\frac{r_2 r_3}{r_1 r_4}\right) - H_o \sin\beta \, (\emptyset_1 - \emptyset_2 - \emptyset_3 + \emptyset_4)\right\} \quad (2)$$

where Z is the vertical magnetic field, H is the horizontal magnetic field, H is the azimuth angle, I is the inclination angle.

$$\begin{aligned} r_1^2 &= d^2 + (x + d\cot\alpha)^2 \\ r_2^2 &= D^2 + (x + D\cot\alpha)^2 \\ r_3^2 &= d^2 + (x + d\cot\alpha - b)^2 \\ r_4^2 &= D^2 + (x + D\cot\alpha - b)^2 \end{aligned} \quad (3)$$

$$\begin{aligned} \emptyset_1 &= \tan^{-1}[d/(x + d\cot\alpha)] \\ \emptyset_2 &= \tan^{-1}[D/(x + D\cot\alpha)] \\ \emptyset_3 &= \tan^{-1}[d/(x + d\cot\alpha - b)] \\ \emptyset_4 &= \tan^{-1}[D/(x + D\cot\alpha - b)] \end{aligned} \quad (4)$$

Here, a prism with top depth d, bottom depth D, width b, distances from each vertex to the observation point r_1, r_2, r_3, r_(4,) and tangent angle ∅_1, ∅_2, ∅_3, ∅_4 for each vertex. The total magnetic field is given by the equation (5)

$$F = 2k\{H \sin\beta \cos I + Z \cos I\} \quad (5)$$

3.2. Normalized Full Gradient Method (NFG)

The NFG technique is based on the downward analytical continuation of potential field data and analytical signal amplitude. As is known, all potential sources are located below the measuring plane. Potential field data recorded in a given plane can theoretically be calculated on a plane above or below the measurement plane if there is no source. In a potential field data, although it is possible to make an analytical continuation upwards (outside the mass) to the desired height, it is not possible to make an analytical continuation downwards as much as desired in the environment of the mass causing the anomaly.

The extension can be applied to the data up to the closest point of the source, in other words, up to its top surface. Because after this point, some singular points are encountered. So downward analytical continuation is only made up to this maximum depth where the singular point is. From this point of view, the downward analytical continuation values of the potential field data show irregular changes while passing the body, which causes an anomaly. The initial value of these irregular variations indicates the depth to the upper surface of the body causing the anomaly. The downward analytical continuation is a useful assessment method for identifying shallow sources.

Nabighian (1972) [44] showed that the amplitude of potential field data can be described by the following equation.

$$G(x) = \sqrt{F_x^2(x) + F_z^2(x)} \quad (6)$$

Here, F(x) represents the potential field data, and, F_x (x) and F_z (x) represent the horizontal and vertical derivatives of the magnetic anomaly, respectively. The mathematical basis of the NFG technique is the G_T (x,z) operator. In general, the NFG amplitude at a given point is expressed by the following equation [3, 45].

$$G_T(x_i, z_j) = \frac{\sqrt{\left[F_x^2(x_i,z_j)+F_z^2(x_i,z_j)\right]^v}}{\frac{1}{M}\sum_{i=1}^{N}\sqrt{\left[F_x^2(x_i,z_j)+F_z^2(x_i,z_j)\right]^v}} \quad (7)$$

Where G_T (x,z) is the NFG's amplitude at a specific point (x_i,z_j), z_j is the downward continuation level, (i = 0, 1, 2, 3,. . ., M; j = 0, 1, 2, 3,. . .,z). The function F(x,z) expresses the magnetic field along the x-axis and analytical continuation is made along the z-axis at Δz intervals. M is the number of points in the profile, and the functions F_x (x) and F_z (x) are derivatives of F(x,z) along the x and z axes. v is the degree of the NFG operator. The full gradient term is expressed as the sum of the horizontal gradient F_x (x,z) and the vertical gradient F_z (x,z). The term NFG, on the other hand, refers to the division of the full gradient of equation 6 by the arithmetic mean value.

In order to protect small frequency components in potential field data, the subharmonic value is usually taken as 1. The upper harmonic limit value is usually found by trial and error. For this purpose, N=10, 20, 30, and 40 values were used within the scope of the study. For each harmonic value, the appearance of NFG cross-sections was observed. It is desirable that there are no sharp transitions between the maximum and minimum contour closures in NFG sections and the absence of multiple local minimum closures. If the NFG contour values are greater than 1, they are taken to be the maxima. On the contrary, if those are smaller than 1 represent the minima [16]. Sındırgı and Özyalın (2019) [12] developed a new criterion instead of trial and error method to determine the most appropriate harmonic number. In their article, they obtained the optimum harmonic number by calculating the minimum error values corresponding to different harmonic numbers.

3.3. Calculation of the NFG operator

The calculation of the NFG operator can be performed using a Fourier series approximation of the function F(x,z) along the x-axis in the range (-L,L) given by Bracewell (1984) [46] and Blakely (1995) [47].

$$F(x,z) = \sum_{n=0}^{\infty}\left[A_n \cos\left(\frac{\pi n x}{L}\right) + B_n \sin\left(\frac{\pi n x}{L}\right)\right] e^{\frac{\pi n z}{L}} \quad (8)$$

The basis of this method is the use of Fourier series. Analytical continuation operation for any z-plane of a harmonic function given in the interval [0,L] can be written as a Fourier sine series.

$$F(x,z) = \sum_{n=1}^{N} B_n \sin\left(\frac{\pi n x}{L}\right) e^{\frac{\pi n z}{L}} \quad (9)$$

Here; B_n is the Fourier sine coefficient, n is the harmonic number, L is the length of the profile, z is the plane on which the analytical continuation is made. With the help of equation 9, it is possible to calculate the F(x) function above or below a given plane.

When the first-order derivatives of the F(x,z) function defined in equation 9 are taken in the x and z directions, F_x (x,z) and F_z (x,z) are defined by the following equation.

$$F_x(x,z) = \frac{\pi}{L}\sum_{n=1}^{N} nB_n \cos\left(\frac{\pi n x}{L}\right) e^{\frac{\pi n z}{L}} \quad (10)$$

$$F_z(x,z) = \frac{\pi}{L}\sum_{n=1}^{N} nB_n \sin\left(\frac{\pi n x}{L}\right) e^{\frac{\pi n z}{L}} \quad (11)$$

The B_n sine coefficients in equation (11) can be found with the help of the following equation.

$$B_n = \sum_{n=1}^{N} F(x,z) \sin\left(\frac{\pi n x}{L}\right) \quad (12)$$

To eliminate the Gibbs effect resulting from downward continuation process, a smoothing factor (q) can be defined as follows. This term is called the Lanczos smoothing operator.

$$q = \left[\frac{\sin\left(\frac{\pi n}{N}\right)}{\frac{\pi n}{N}}\right]^{\mu} \quad (13)$$

where μ is any integer number and the degree of smoothing.

4. Experimental Results

In this section, the NFG technique was applied to synthetic magnetic data generated from prismatic-shaped models mostly used in magnetic methodology to investigate the effectiveness of the method. A synthetic prism model was calculated to test the effect of the suggested technique on the determination of location parameters such as the depth of the structure center and its distance from the origin. The synthetic models were calculated by the method of Telford et al. (1976)[43] for a prismatic-shaped 2D body. Trials were made on three different models to examine the NFG field depending on the width and thickness variation of a magnetic prism. For all of the four prismatic-shaped synthetic models, the profile length was chosen as 40 m. Likewise, inclination, declination, azimuth angle, and magnetization intensity values were defined for all four prismatic-shaped synthetic models. These values were taken as 60o, 0o, 0o, and 1 A/m [SI], respectively.

4.1. Synthetic Model #1

The parameters of synthetic Model #1 and the model parameters obtained from the NFG technique are shown in Table 1. Synthetically generated ΔT(x,0) curves and NFG sections are given in Figure 3.
NFG technique with different harmonic numbers is applied to the synthetic anomalies of a prismatic model. It is observed that the NFG technics produces closed contours around the anomalous body for all harmonic intervals. They are the depths of the maximum singular points in the NFG sections calculated for various harmonics. The center of the completely closed contours of the NFG harmonics corresponds to the actual burial depth of the structure. In Table 1, the structural parameters of this model and largest singular point value (LSPV) of the NFG field, the depth in the z-axis, and the horizontal distance in the x-axis for the N=10, 20, 30, and 40 harmonics are given. Figure 3 shows that the NFG technique precisely determines the surface projection point of the structure (x = 20.5 m) at various harmonic numbers. In addition, the structure depth was obtained exactly (h=1.5m) at the 40th harmonic number

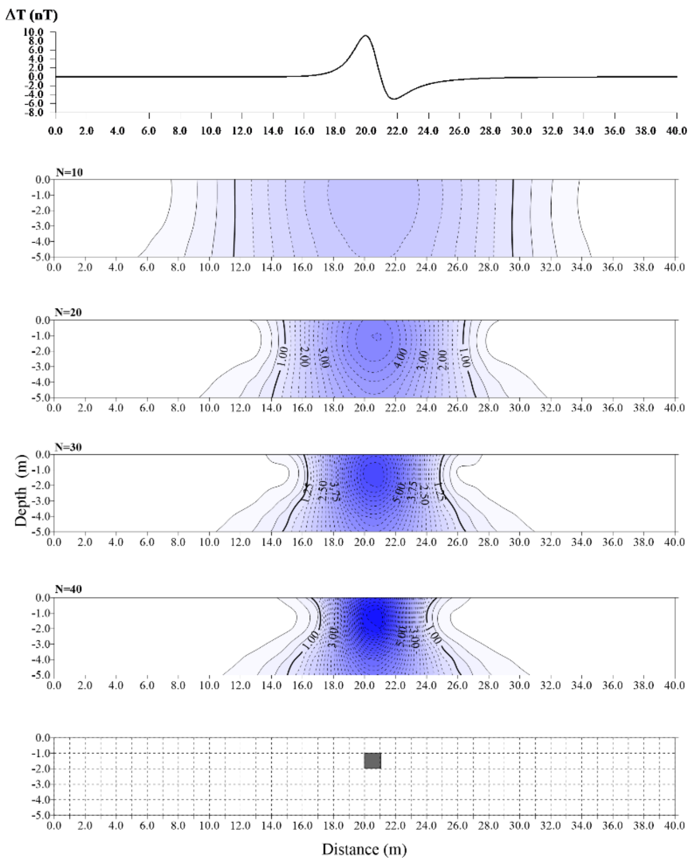

Figure 3. Synthetic anomaly and NFG sections for a single 2D synthetic prism model #1 for various harmonics

4.2. Synthetic Model #2

Model#2 was created to see the effect of the NFG technique on the solution with the increase of the structure width. The parameters of synthetic Model #2 and the model parameters obtained from the NFG technique are shown in Table 2. In this application, the top surface depth, thickness, and distance to the origin parameters of the structure in Model #1 are used exactly. In Model #2, only the width of the structure has been increased.
In Model #2, the prism width is defined as 11.0 m. The magnetic anomaly and NFG sections of the model are shown in Figure 4. Due to the increase in model width in all NFG sections with different harmonic numbers, positive closures are observed completely independently of each other at horizontal distances corresponding to the boundaries at both ends of the structure.
There are negative closures in the direction of the extension of the structure. This detail is clearly observed in the 40th harmonics. The depth of the

structure and their distance from the origin were found clearly on both sides.

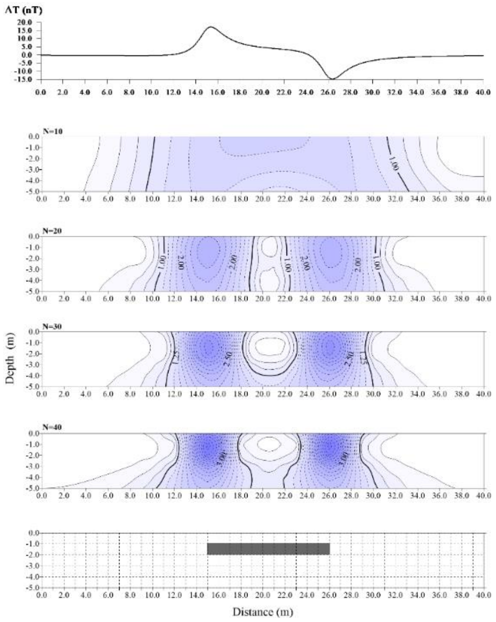

Figure 4. Synthetic anomaly and NFG sections for a single 2D synthetic prism Model #2 for various harmonics

4.3. Synthetic Model #3

In this section, we wanted to see the effect of the structure thickness on the solution in the NFG solution. Model #3 was generated to see the effect of the NFG technique on the solution with the increase of the structure thickness. The parameters of synthetic Model #3 and the model parameters obtained from the NFG technique are shown in Table 3. In this section, the top surface depth, width, and distance to the origin parameters of the structure in Model #2 are used exactly. In Model #3, only the thickness of the structure has been increased. There are negative closures in the direction of the extension of the structure (Figure 5). While in the previous Model #1 and Model #2 studies, the singular point values corresponded to the center of the structure, it is observed that the singular points in the NFG sections for different harmonics are concentrated towards the upper surface of the structure with the increase in thickness in Model #3.

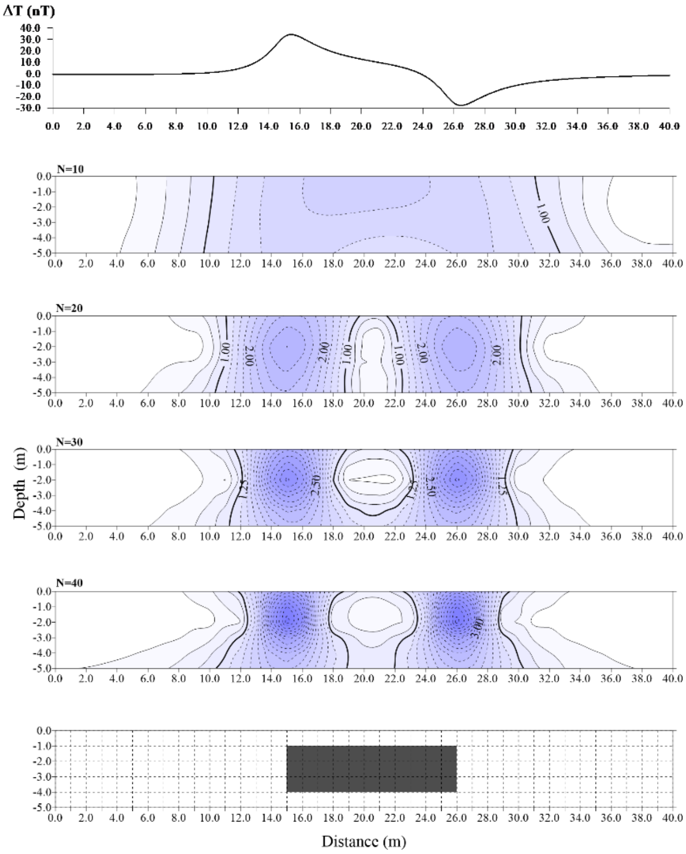

Figure 5. Synthetic anomaly and NFG sections for a single 2D synthetic prism model #3 for various harmonics

4.1. Synthetic Model #4

The model under consideration is three magnetic prisms in contact with each other at the same depth (Fig. 6). The angles of inclination, declination, and azimuth used in the previous three models are also used in Model #4. However, while the magnetization intensity of Prism #1 and Prism #3 is 1 A/m [SI] in the calculations, the magnetization intensity of Prism #2 in the middle is 1.5 A/m [SI].The purpose of choosing the model is to examine NFG solutions by comparing them to geological structures in contact with different magnetization intensities. NFG sections for the magnetic anomaly of this model and different harmonics calculated from this anomaly are shown in Figure 6. The structural parameters of this model are given in Table 4. When the NFG cross-section at the 40th harmonic in Figure 6 is examined, positive closures are observed in the horizontal distances corresponding to the borders at the two ends of the structures, due to the wide increase in the width of the model compared to its thickness. There are negative closures in the direction of the extension of the structure. This detail is clearly observed in the 40th harmonics.

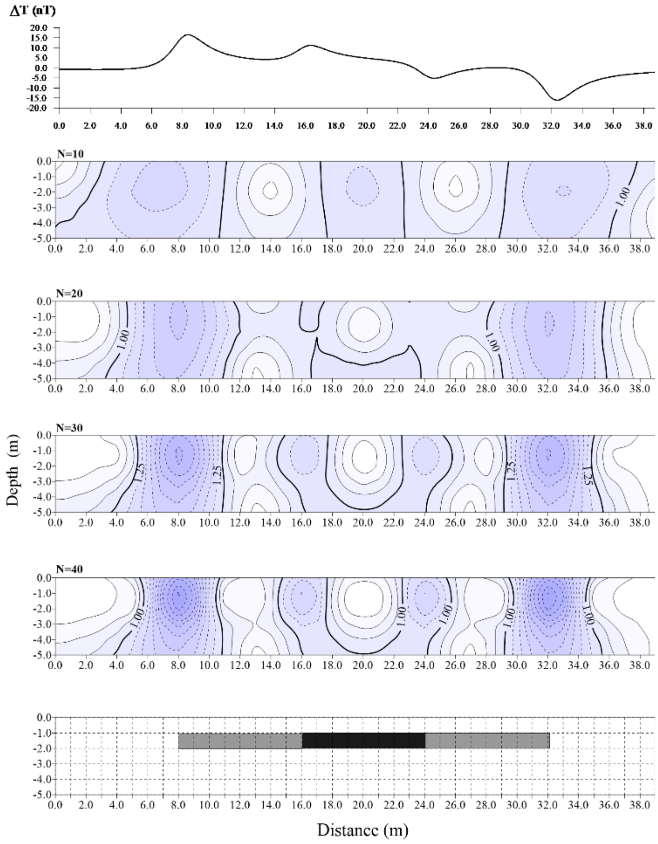

Figure 6. Synthetic anomaly and NFG sections for multi-body 2D synthetic prism Model #4 for various harmonics

Table 1. The best model parameters obtained from the NFG for synthetic Model #1

MODEL 1	**Depth (m)**	**Thickness (m)**	**Width (m)**	**Distance (m)**
	1.0	1.0	1.0	20.5
		Harmonic Number (N)		
	10	**20**	**30**	**40**
LSPV	2.45	4.86	7.27	9.96
Distance (m)	20.5	20.5	20.5	20.5
Depth (m)	1.1	1.4	1.4	1.5

Table 2. The best model parameters obtained from the NFG for synthetic Model #2

MODEL 2	**Depth (m)**	**Thickness (m)**	**Width (m)**	**Distance (m)**
	1.0	1.0	11.0	20.5
		Harmonic Number (N)		
	10	**20**	**30**	**40**
LSPV	1.85	2.98	4.40	5.60
Distance (m)	15.0-26.1	15.0-26.1	15.0-26.1	15.0-26.1
Depth (m)	1.1	1.4	1.4	1.5

Table 3. The best model parameters obtained from the NFG for synthetic Model #3

MODEL 3	**Depth (m)**	**Thickness (m)**	**Width (m)**	**Distance (m)**
	1.0	3.0	11.0	20.5
	Harmonic Number (N)			
	10	**20**	**30**	**40**
LSPV	1.86	3.00	4.48	5.70
Distance (m)	15.0-26.1	15.0-26.1	15.0-26.1	15.0-26.1
Depth (m)	4.1	2.0	1.8	1.3

Table 4. The best model parameters obtained from the NFG for synthetic Model #4

MODEL #4	**Prism #1**	**Prism #2**	**Prism #3**
Depth (m)	1.0	1.0	1.0
Thickness (m)	1.0	1.0	1.0
Width (m)	8.0	8.0	8.0
Distance (m)	12.0	20.0	28.0

5. Field Examples

In the Hittite city of Sapinuwa, the first search started in 1998 with resistivity studies. Since the study area has suffered a great fire several times in history, magnetic measurements were carried out with the thought that the magnetic method could yield more appropriate results here. Total magnetic field data was collected using Scintrex Smartmag brand magnetometer. The orientation of each profile was chosen from south to north and the direction of the sensor was oriented towards north. The sensor height was chosen as 0.50 m. In order to define the study area, measurements were carried out by selecting small independent areas, and in later studies, measurements were carried out in a large area consisting of adjacent areas.

5.1. Site #1

In this area with dimensions of 15*15 m, the profile spacing is 1.0 m and the measuring spacing in each profile is 1.0 m. When the total magnetic field anomaly obtained is examined, the first point that draws attention is a difference of approximately 130 nT between the positive and negative closures in the W-E direction in the middle of the field, and similarly a difference of approximately 160 nT in the N-S direction (Figure 7).

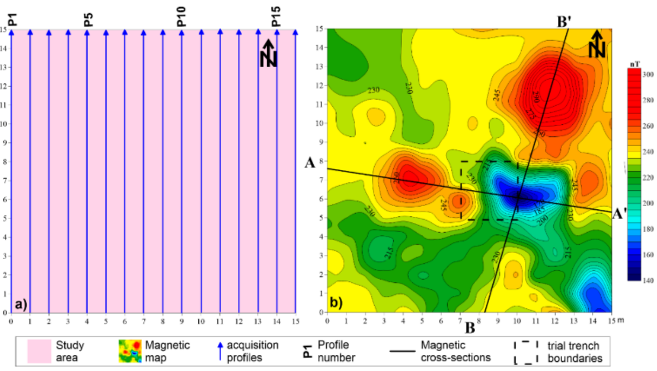

Figure 7. (a) Magnetic survey area and data acquisition profiles, (b) Magnetic anomaly map of the studied Site #1 and NFG sections

In this study area, firstly, a 15 m long AA' section in the W-D direction to cut the closures and a 15 m BB' section in approximately S-N direction were taken. NFG technique was applied to the data obtained from AA' and BB' sections (Figures 8). When both figures were examined, an average depth of approximately 1.0 m was found. As a result of the evaluation of the magnetic anomaly map of the area with the NFG technique, LSPV locations are shown in Figure 8.

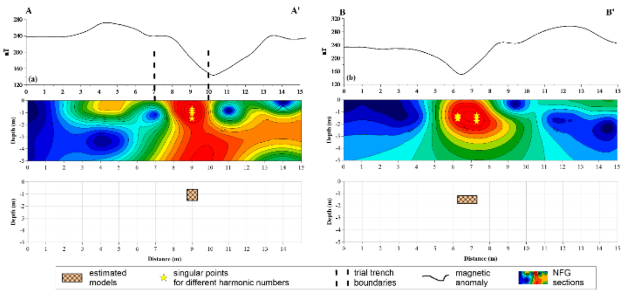

Figure 8. An application of the NFG technique to the magnetic anomalies obtained from Site #1

A trial trench is proposed in the 3*3 m area indicated by the black dashed line in Figure 7. Successful geophysical results were obtained at the end of the excavations at the proposed site. During the excavation, wall ruins were found 0.70 m below the surface extending approximately SW-NE in the western part of the trench. At the later stage of the excavation, these ruins were cleared and the foundation part of the wall was reached at approximately 1.0 m. Likewise, in the NFG section in Figure 8, the proposed trench boundaries are shown with a black dashed line. The foundations of the building obtained at the end of this trench are shown in Figure 9.

Figure 9. The wall remains unearthed in the proposed trial trench at Site #1.

5.2. Site #2

The dimensions of the Site #2 search area are 14*26 m. The distance between the profiles is 1.0 m and the measuring range in each profile is 1.0 m. When the total magnetic field map obtained in Site #2 is examined, positive and negative closures extending in the S-N direction are observed (Figure 10). The dimensions of our working area are 14*26 m, 1.0 m between profiles, and the measuring range in each profile is 1.0 m. For this reason, firstly, a 25 m long AA' section was taken in the S-N direction to cut the closures. NFG technique was applied to the magnetic anomaly of the AA' section (Figure 11).

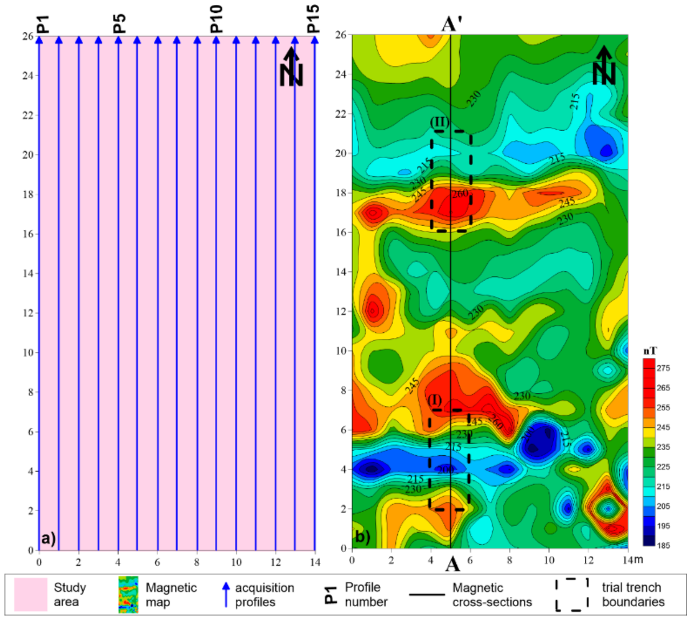

Figure 10. Magnetic survey area and data acquisition profiles, (b) Magnetic anomaly map of the studied Site #2 and NFG sections

When the NFG section was examined, it was observed that there were two separate structures. Symbols with yellow asterisks show singular point values for different harmonic numbers. It starts from about 1.0 m and reaches up to 1.7 m. A trial trench is proposed in two separate areas of 2*5 m, indicated by the black dashed line in Figure 10. The foundations of the building obtained at the end of this trench are shown in Figure 12.

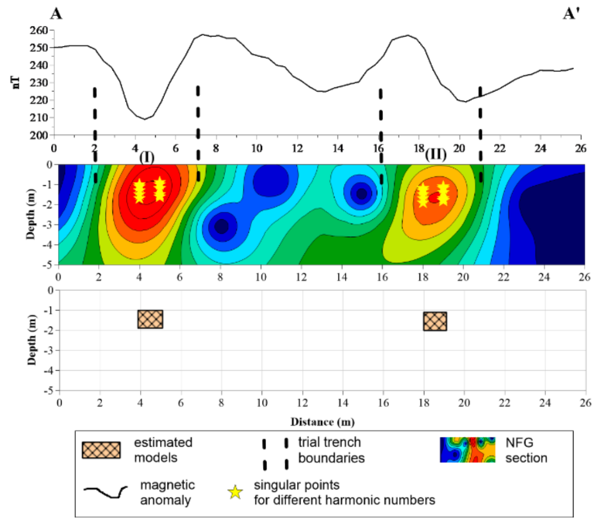

Figure 11. An application of the NFG technique to the magnetic anomalies obtained from Site #2

Figure 12. The wall remains unearthed in the proposed trial trench at Site #2.

6. Results and Discussion

The NFG technique is based on downward analytical continuation, and the NFG technique applied to magnetic field data gives direct information about the location and depth of buried structures in archaeological sites.

NFG cross sections were calculated for harmonics N = 10, 20, 30 and 40 (Figure 3). In the middle part of the profile, inclusions start to appear, although they are not obvious around the singular point value (2.45) at the N=10 harmonic. Contour inclusions become more frequent at N = 20 and 30 harmonic. The maximum singular point value (9.96) becomes the most prominent at the N=40 harmonic. In case of an increase in the width of the structure, no significant inclusion is observed in the N=10 harmonic (Figure 4). With the increase of the harmonic number, the maximum inclusions are concentrated on the two sides of the structure, while the minimum inclusions are observed in the middle part of the structure. In case of an increase in the thickness of the structure, no significant inclusion is observed in the N=10 harmonic, similar to the previous model (Figure 5). In N=30 and 40 harmonics, while the maximum inclusions are concentrated on the two sides of the structure, minimum inclusions are observed in the middle part of the structure. In three different structure models, while maximum inclusions are concentrated at the edges of the structures in all harmonics, minimum inclusions are observed in the middle of the structures (Figure 6).

Two NFG applications were performed by taking sections AA' and BB' from the Site #1 magnetic map (Figure 8a and b). In both NFG applications, singular point values for different harmonic values are shown with yellow asterisks. While the singular point values for the AA' section are positioned at approximately 9m in the horizontal position, it is observed that they vary between 0.7-1.5m in the vertical axis. The fact that it does not change in the horizontal axis indicates that the width of the structure is narrow (figure 8a). On the other hand, it is possible to say that the structure is slightly wider and deeper in the distribution of individual point values in section BB' (Figure 8b)

NFG was applied by taking a section from the Site #2 magnetic map (Figure 11). The observation of a maximum closure between the two minimums in the left and right parts of the NFG section from the NFG application indicates that there are two different structures. It is observed that structure depth starts from about 1.0 m and reaches up to 1.7 m.

Singular points were detected with better precision at higher harmonics than at lower harmonics for shallow depths. When synthetic model studies are examined, as the structure width increases according to structure thickness, the singular values shift towards the structure boundaries instead of the structure center.

7. Conclusion and Suggestions

In the present study, 2D NFG technique was used to detect the location of a 2D prismatic-shaped. The method was applied to both synthetic and field datasets. The performance and reliability of the NFG technique were tested on the synthetic magnetic data. The solution efficiency of this method was investigated according to different structure properties (e.g. width, thickness). Especially, the NFG technique has been applied to multiple structure models. As a result of the evaluation, the method can define the structures correctly (location and depth). In archaeological sites, this finding helps overcome the problem of locating buried multi-structures.

The field data used in the present study are also acquired at Sapinuwa ancient site in Çorum, Turkey. The NFG technique was applied to three magnetic profiles obtained from the magnetic maps of two separate areas at Sapinuwa ancient site. After evaluation of the NFG technique of three magnetic profiles obtained from the two sites, search trenches were proposed. When the location parameters of the ruined structures obtained by the proposed method in this study are compared with the results of the archaeological excavations, they show a good agreement with each other. For these data sets, the estimated depths are very close to the depths measured from archaeological excavations. It can be said that this method, applied to the magnetic data set collected from archaeological sites, produces successful and effective results.

Acknowledgment

This study is part of the PhD thesis named "Potansiyel alanlarda Otomatik Değerlendirme Teknikleri ve Arkeolojik Alanlara Uygulanması, (2003)" of Şenol Özyalın. I would like to thank Prof. Dr. Aygül Süel and Dr. Mustafa R. Süel, who directed the excavation of the ancient city of Sapinuwa for providing valuable support during the collection of magnetic data. Thanks are due to Prof. Dr. Rahmi Pınar for helping. We also owe special thanks to three anonymous referees.

Conflict of Interest Statement

There is no conflict of interest between the authors**.**

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

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