BOLLETTINO DI GEOFISICA TEORICA ED APPLICATA VOL. XXVII, N. 105 - MARZO 1985

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RESPONSE CHARACTERISTICS OF CENTRAL FREQUENCY SOUNDING OVER A MULTI-LAYER EARTH

Summary. Digital filter method is applied to computation of multi-layer central frequency sounding (CFS) response. Two-, three-, four- and five-layer earth models are considered and the corresponding responses computed. Resolution of layer parameters and applicability of CFS systems over a multi-layer model are discussed. Studies indicate that the performance of CFS system up to three to four-layer cases is satisfactory while for more than four layers resolution is poor even for significant conductivity contrasts. Although this limits the applicability, CFS is expected to be quite useful for shallow investigations in hard rock areas, normally not involving more than three layers.

Riassunto. Il metodo di filtraggio digitale viene applicato per il calcolo della risposta di sondaggi multistrato a frequenza centrale. Sono stati considerati modelli di terra a 2, 3, 4 e 5 strati e sono state calcolate le corrispondenti risposte. Vengono discussi la risoluzione dei parametri caratterizzanti gli studi e l'applicabilità del sistema CFS su di un modello multistrato. Gli studi sviluppati indicano che le prestazioni del sistema CFS sono soddisfacenti fino al caso di 3 o 4 strati mentre per più di 4 strati la risoluzione è scarsa anche per significativi contrasti di conduttività. Sebbene questo fatto limiti la sua applicazione, il sistema CFS sembra essere utile per prospezioni superficiali in aree con roccia compatta, in cui di solito la schematizzazione a 3 strati è sufficiente.

Received March 26, 1984

1. Introduction

Multi-frequency electromagnetic depth sounding is used to solve groundwater and mineral exploration problems in hard formations. Loop source method CFS (Patra, 1967; Patra & Mallick, 1980) is considered in the present study. While Patra (1970, 1976 & 1978) restricted the study only to two-layer cases, Shastri (1981) extended it to multi-layer earth models through digital linear filter (Shastri & Patra, 1983; Patra & Shastri, 1983a, 1983b). Linear filter theory applied by Verma (1973, 1977) for dipole frequency sounding is utilized here in computing CFS response.

2. Statement of the problem

Studies carried out by Shastri (1981), Shastri & Patra (1983) and Patra & Shastri (1983b) with reference only to two- and three-layer earth models have established the utility and applicability of CFS. In the present study, computation of theoretical CFS response over a generalised earth model for different loop radius is considered. Performance of CFS system is studied through an analysis of sets of curves for a number of loop radii at varying conductivity contrasts.

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3. Formulation and the theoretical curves

The normalized magnetic field (h_z) for CFS system placed over a horizontally stratified earth may be expressed (Shastri & Patra, 1983; Patra & Shastri, 1983b) as (Fig. 1):

$$h_z = a^2 \int_o^\infty [\, 1 + F\,(m,\, h_j,\, \sigma_j,\, f)\,]\, J_1\,(ma)\; m\,dm \qquad (1)$$

with usual notations. Eq. (1) can be written in a suitable form to evaluate the integral with the help of digital linear filter. A multi-layer earth model shown in Fig. 1 is considered to compute CFS response curves for two-, three-, four- and five-layer cases.

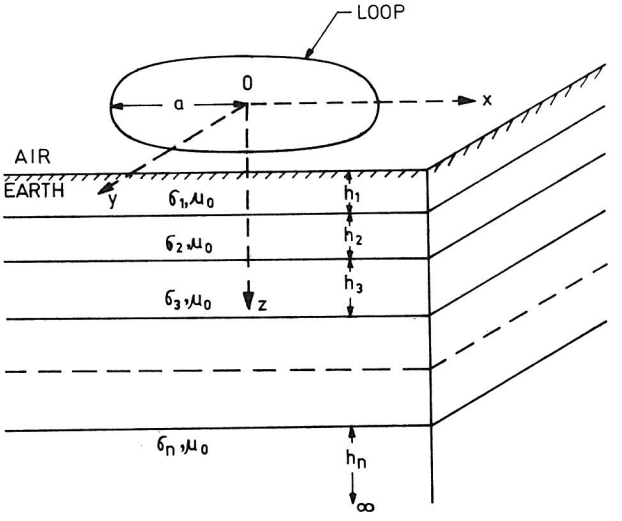

Fig. 1 — Circular loop over a multi-layer earth.

The corresponding kernel functions can be computed from the following recurrence relations (Koefoed et al., 1972; Verma, 1977):

$$F_{(j-1),\, n(m)} = \frac{M_{(j-1),\, j} + F_{j,\, n(m)}\; e^{-2h_j m_j}}{1 + M_{(j-1),\, j}\; F_{j,\, n(m)}\; e^{-2h_j m_j}} \qquad (2)$$

and

$$F_{n,\, n(m)} = 0 \qquad (3)$$

with

$$m_j = (m^2 + k_j^2)^{1/2}; \qquad M_{j,\, 1} = \frac{m_j - m_1}{m_j + m_1} \qquad (4)$$

Using logarithmic scales defined by

$$x = ln\,(a); \qquad y = ln\,(1/m),$$

eq. (1) may be expressed in the form

$$h_z = 1 - \int_0^\infty e^{2(x-y)} F(y, h_j, \sigma_j, f) J_1(e^{x-y})\, dy \tag{5}$$

Eq. (5) involves the convolution sum of product of the following two functions:

$$\text{input function} = -e^{x-y} F(y, h_j, \sigma_j, f) \tag{6}$$

$$\text{filter function} = e^{x-y} J_1(e^{x-y}) \tag{7}$$

Following the procedure and using the same filter coefficients as given in Shastri (1981), Shastri & Patra (1983) and Patra & Shastri (1983b), CFS response is computed for multi-layer earth.

Several models are considered for computation and sets of album of curves prepared (Shastri, 1981). Only one set each of two-, three-, four- and five-layer cases is presented here. The parameters used for computation are noted on the diagrams. Subsequent layer situations are obtained through step-by-step introduction of extra layers to the previous models as evident from the diagrams.

Computed amplitude data are presented on bilogarithmic scales against conductivity parameter B (Figs. 2-5) which is a function of frequency, conductivity and loop radius. These sets of multi-layer response curves are presented with loop radius as curve parameter. Fig. 6 presents model curves for a fixed loop radius but for varying situations, drawn from Figs. 2-5.

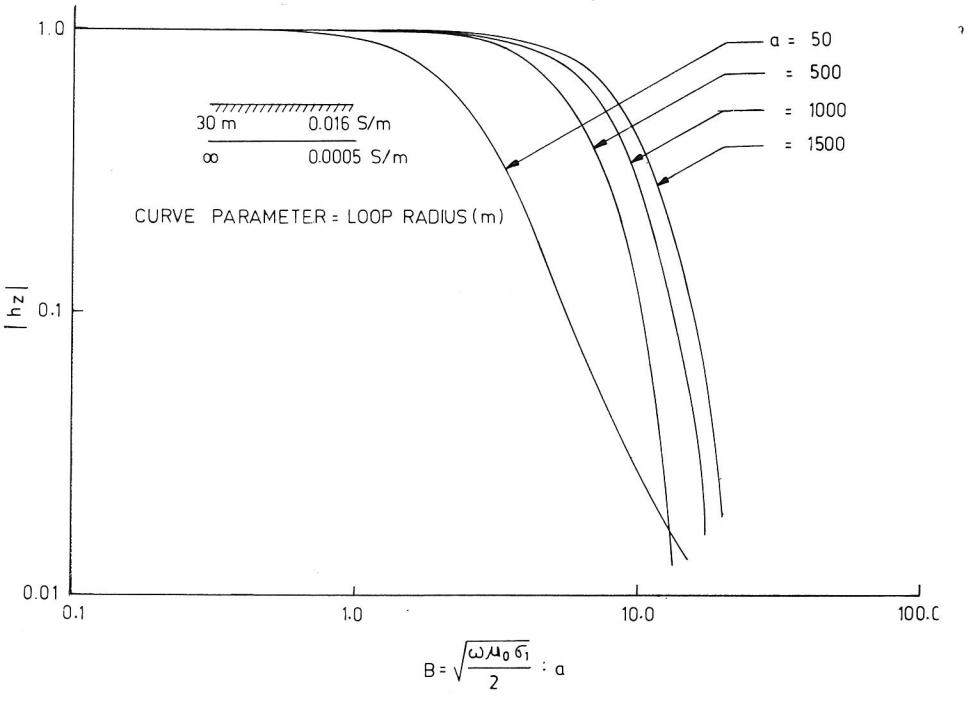

Fig. 2 — Amplitude response curves for a two-layer earth.

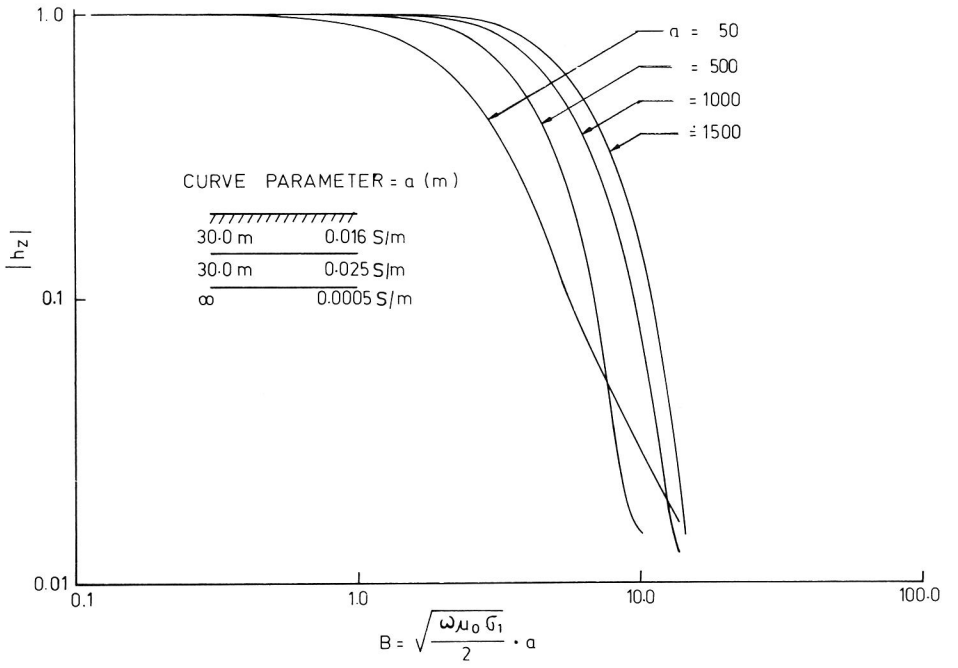

Fig. 3 — Amplitude response curves for a three-layer earth.

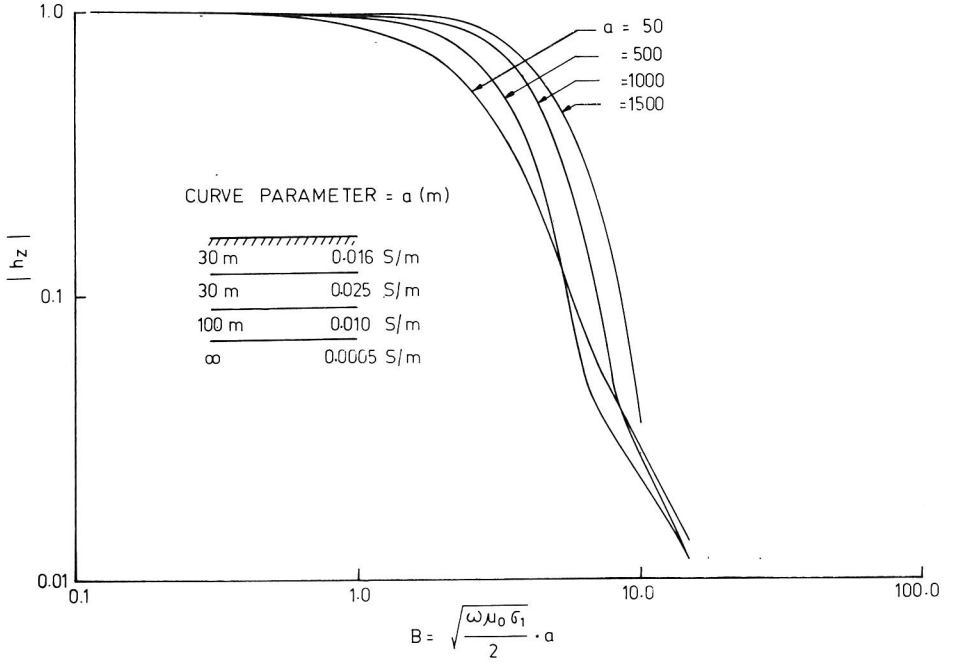

Fig. 4 — Amplitude response curves for a four-layer earth.

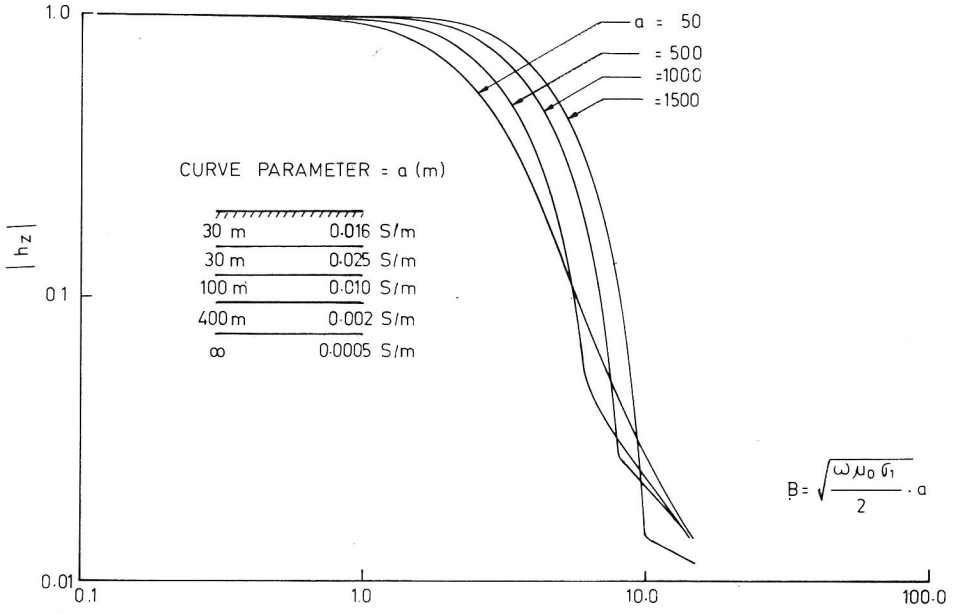

Fig. 5 — Amplitude response curves for a five-layer earth.

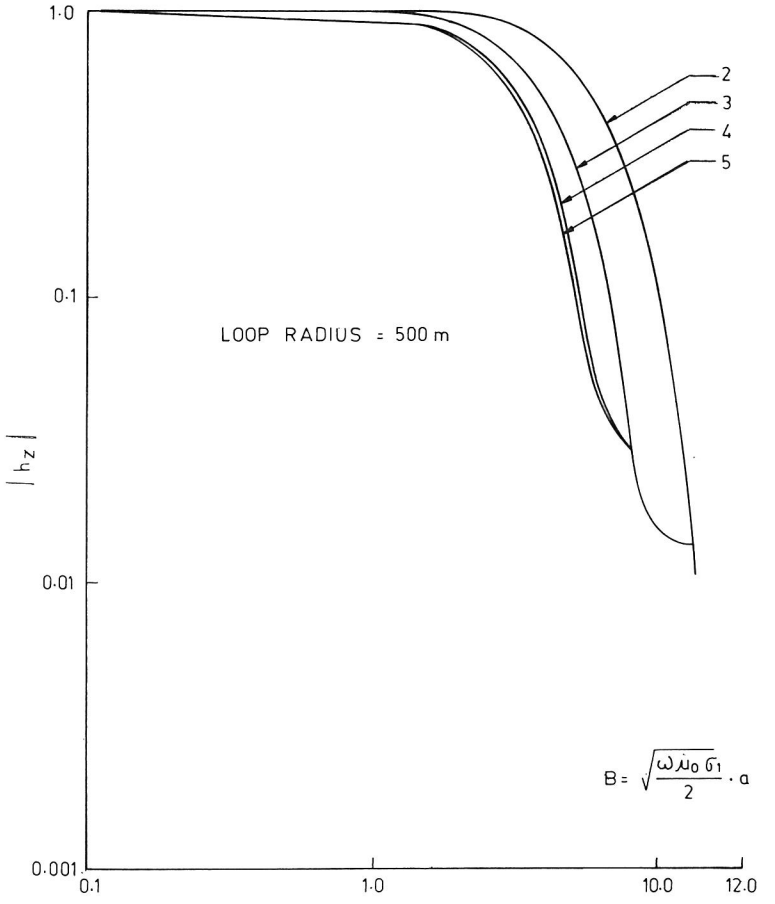

Fig. 6 — Amplitude response curves for a layered earth (2 - two-layer; 3 - three-layer; 4 - four-layer; 5 - five-layer).

4. Discussions

Computation of CFS response has been made for varying loop radii. A sharp fall of amplitude (Fig. 2) at larger value of loop radius indicates the existence of a resistive second layer. The presence of an intermediate conductive layer is not reflected well on the response curves for three-layer *H*-type model (Fig. 3), even with higher values of loop radius. Responses presented in Figs. 4 & 5 respectively for *HA* and *HAA* type cases indicate a poor resolution of layer parameters even at larger loop radius. Multi-layer responses presented for a fixed value of loop radius in Fig. 6, shows that the resolution is not satisfactory for models involving more than four layers.

5. Conclusion

A study of CFS response curves computed for two- and three-layer earth models establishes the applicability and accuracy of the method with a meaningful resolution of layer parameters. Studies over models consisting of four layers or more show that frequency-domain responses give a poor resolution of layer parameters except for a very large conductivity contrast.

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