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Negative Induced Polarization Effects for Two-Dimensional Structures

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Abstract : Negative induced polarization (IP) responses are examined for two-dimensional structures using a modeling technique with finite difference method. Percent frequency effect is used for IP parameter because it can be efficiently computed by a perturbation method. Thin conductive, polarizable overburden causes obvious negative IP responses on IP pseudosection. This fact means that IP responses from resistive, polarizable body below the overburden can be masked solely as a function of the resistivity distribution. Resistive, non-polarizable body below the overburden, however, can be detected by the negative IP responses.

INTRODUCTION

Since induced polarization (IP) effects in rocks are defined as positive values, remarkable negative IP responses in field data are frequently regarded as a failure of measurement. However, Bartin (1968) reported that in time-domain IP measurements the anomalous negative IP exists in a layered earth. Roy and Elliot (1980) showed that the negative IP is found in a zone with saline water layer.

Based on Seigels' theory (Seigel, 1959), Nabighian and Elliot (1976) revealed that negative IP effects can occur whenever the geoelectric section is of type K or Q. Kim (1978) calculated IP responses for a layered earth model by means of a digital linear filter developed by Anderson (1979) in order to examine the negative IP phenomena. As a result, it is found that the negative IP appears when the first layer is polarizable in the section of type K or Q, and the polarizabilities of the other layers depress the negative IP.

Dipole-dipole IP field data are usually represented by a pseudosection. In this case, a careful interpretation of IP date is required because the polarizability of the first layer produces negative IP responses in deeper plotting point as shown by kim(1987). In this paper, negative IP responses are examined for two-dimensional (2D) geoelectric structures, and a problem associated with the pseudosectional representation of data is pointed out. The IP responses for 2D structures are obtained from 2D modeling technique using finite difference method with 69×13meshes (Kim, 1986). All of the IP effects used in this paper are represented by percent frequency effect, and an efficient procedure of computation is also introduced here.

COMPUTATION OF IP RESPONSE

IP response is computed either as percent frequency effect (PFE or F. E.) or phase(θ). For PFE, apparent resistivity for a model is computed twice: in the second calculation an intrinsic resistivity of polarizable body is lowered (or raised) by small amount corresponding to its intrinsic PFE. Then the observed PFE (PFE_a)at a receiver is given by

$$PFE = \Delta\rho_a / \rho_a \times 100(\%), \qquad (1)$$

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where $\triangle p_a$ is the change in apparent resistivity due to IP. To compute IP using phase, resistivity of inhomogeneity is specified to a complex value, and the phase of potential difference between receiver electrodes is computed (Hohmann, 1975; Snyder, 1976). Both methods yield the same results, and either can be used to compute chargeability (m) which is a time-domain IP parameter.

Regardless of the IP parameter, the potential in or on the earth should be evaluated. In this paper, finite difference method (FDM) is employed to compute the potential (Kim, 1986). By using the FDM, a generalized Poisson's equation with appropriate boundary condition is reduced to a matrix form

$$[C]\ [\Phi]=[S], \qquad (2)$$

where [C] is the bounded matrix of which terms depend on the conductivity structure, [Φ] is the vector of unknown potentials, and [S] is the vector of source currents. Then the apparent resistivity is given by

$$p_a=G\triangle\Phi/J, \qquad (3)$$

where G is the geometric factor associated with the array used, $\triangle\Phi$ is the potential difference between two electrodes, and J is the source current.

It is not really necessary to calculate apparent resistivity twice or to double the matrix size by making it complex in order to evaluate IP. Since IP can be modeled by slightly changing the resistivity of IP-responsive medium, a perturbation method can be used to avoid the second matrix inversion. If the resistivity of polarizable medium is perturbed, then the matrix equation (2) becomes

$$[C+\triangle C]\ [\Phi+\triangle\Phi]=[S], \qquad (4)$$

where $\triangle C$ and $\triangle\Phi$ are small changes in the coefficient matrix and the solution vector, respectively. Expanding (4) and neglecting the second order term [$\triangle C$] [$\triangle\Phi$] yields

$$[C]\ [\Phi]+[C]\ [\triangle\Phi]+[\triangle C]\ [\Phi]=[S], \qquad (5)$$

Substituting (2) into (5) produces

$$[C]\ [\triangle\Phi]=-[\triangle C]\ [\Phi]. \qquad (6)$$

Since (6) is exactly analogous to (2), the same procedure used to solve [Φ] in (2) is available to solve [$\triangle\Phi$] in (6). This means that one can easily obtain a first order solution of the perturbed problem only by backward substitutions which take practically little computer time.

NUMERICAL RESULTS

Based on the analysis for one-dimensional (1D) layerad earth model (Nabighian and Elliot, 1976; Kim, 1987), a 2D earth model as shown in Fig. 1 is examined in this paper. In the 2D model, the resistivity and thickness of the conductive top layer are assigned to $p_1=1$ and $t_1=0.1$, respectively, and the resistivity and polarizability of the bottom medium are fixed to $p_3=1$ and $PFE_3=0$, respectibely. The polarizability of the top layer (PFE_1), and the resistivity (p_2), polarizability (PFE_2), thickness (t_2)

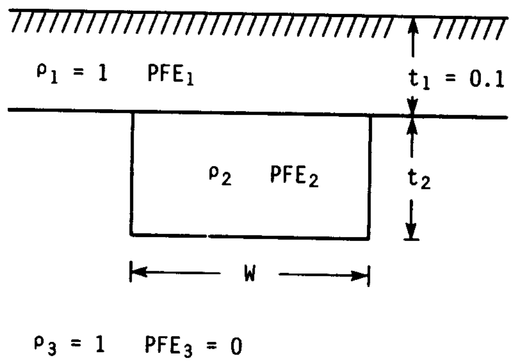

Fig. 1. 2D model examined in this study

and width (W) of the resistive body imbedded in the bottom medium are variables. Here, dipole length is assumed to 1. If W=∞, then the 2D model is reduced to the 1D layered model of type K.

In the geoelectric section of type K, the polarizability of the first layer yields negative IP responses (Kim, 1987). Fig. 2 shows apparent PFE (PFE_a) for three thicknesses of the second layer: t_2=0.2, 0.5 and 0.9. Here, PFE_1=10, PFE_2=0, p_2=10, and W=∞. When the thickness of the second layer is increased, negative IP appears in deeper plotting points, i.e., larger dipole separations (n). Thickening of the second layer produces not only greater positive maximum but also greater negative maximum of IP responses.

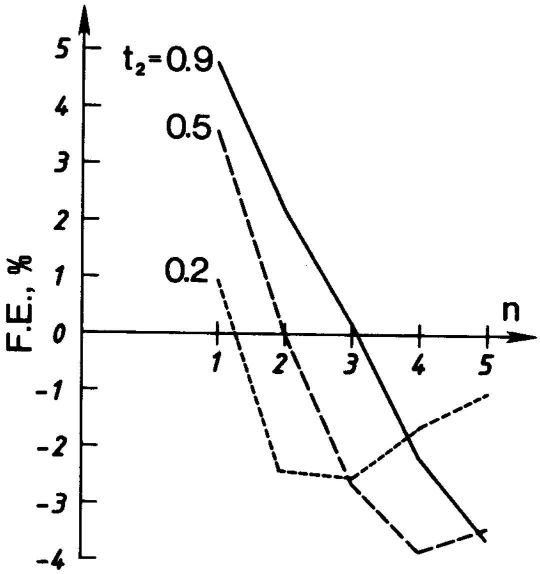

Fig. 2. PFE_a calculated for t_2=0.2, 0.5 and 0.9.

IP responses for variable resistivities of the second layer (p_2=5, 10 and 20)are shown in Fig. 3. The constant values used in Fig. 3 are PFE_1=10, PFE_2=0, t_2=0.2, and W=∞. An increase of the resistivity of the second layer yields not only greater positive maximum but also greater negative maximum of IP respponses. The positive maxima of PFE_a always appear in n's whereas the negative maxima occur in larger n. The n,s associated with the negative maxima depend on the values of ρ_2.

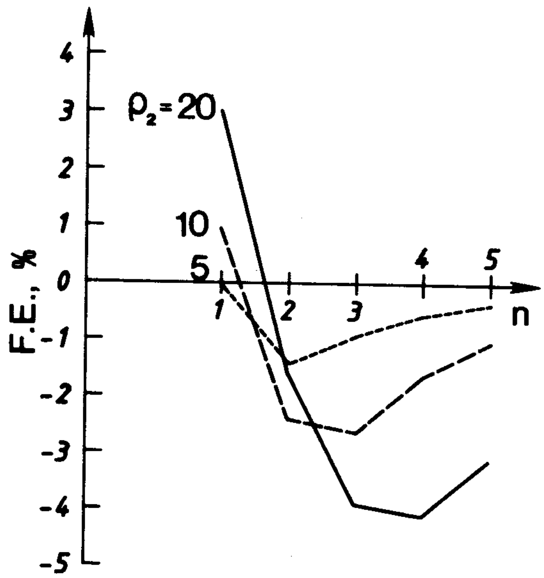

Fig. 3. PFE_a calculated for p_2=5, 10 and 20.

Fig. 4 shows IP responses for variable width of the resistive body (W=2, 4 and 8). The constant values used in Fig. 4 are PFE_1=10, PFE_2=0, p_2=10, and t_2=0.2. An increases of the width of body produces wider region with

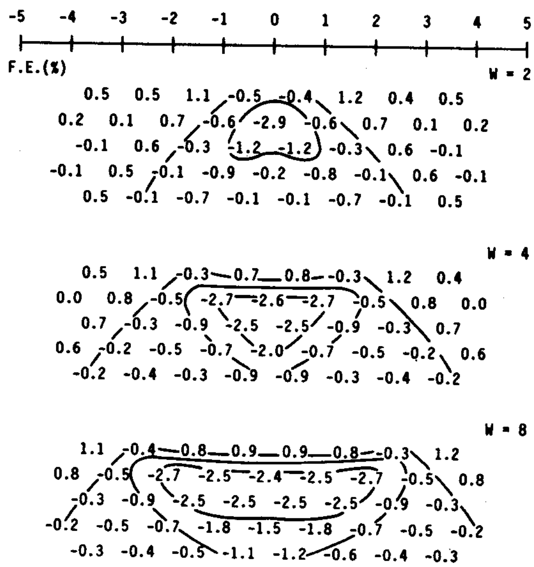

Fig. 4. IP pseudosections calculated for W=2, 4 and 8

negative IP responses in the pseudosection, whereas the values of negative maximum vary little with the change of W. The horizontal length of -1.0% contour almost corresponds with the body width.

IP pattern in pseudosection varies significantly with the polarizability of each medium as shown in Fig. 5. The constant values used in Fig. 5 are $\rho_2=10$, $t_2=0.2$, and $W=4$. The upper pseudosection is computed by assigning the polarizability only to the resistive body, i.e., $PFE_1=0$ and $PFE_2=10$. The middle pseudosection is computed for $PFE_1=10$ and $PFE_2=0$, and the lower one is made for both $PFE_1=10$ and $PFE_2=10$. Obvious negative IP responses occur only for the cases of polarizable top layer. From the upper pseudosection, the resistive, polarizable body may be detected by large positive IP responses. When the conductive overburden is polarizable, the resistive, non-polarizable body may also be recognized by obvious negative IP response as shown in the middle figure. The region with positive anomalies in the lower figure is smaller than that in the upper one because of the negative IP

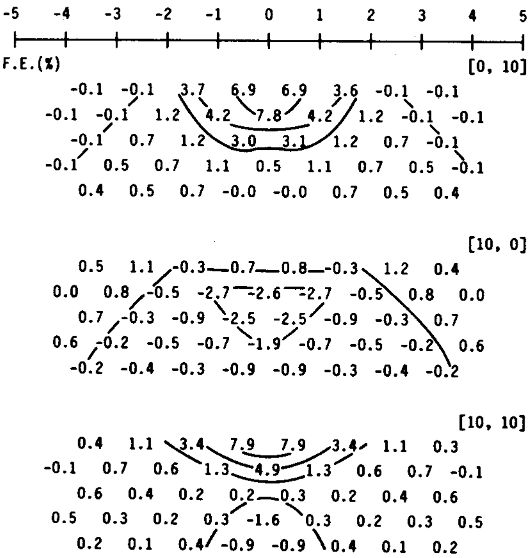

Fig. 5. IP pseudosections calculated for $PFE_1=0$ and $PFE_2=10$(upper), $PFE_1=10$ and $PFE_2=0$(middle), and both $PFE_1=10$ and $PFE_2=10$(lower). Contour interval is 1%.

effects due to the polarizable overburden.

Fig. 6 shows IP responses calculated by simply adding the corresponding values in the upper and middle pseudosections in Fig. 5. In other words, Fig. 6 is an approximate solution made by ignoring an interaction between media 1 and 2. The approximate solution has great resemblance to the lower figure in Fig. 5.

DISCUSSION AND CONCLUSIONS

Since the polarizable top layer (overburden) can produce negative IP responses in deeper plotting points, a serious problem may occur in the native interpretation using a pseudosectional representation of IP data alone. Fig. 4 shows that the negative IP responses are caused by the thin polarizable top layer, and Fig. 5 shows that the positive IP responses of the polarizable body are reformed by the negative IP. Note that the thickness of the polarizable overburden is only 1/10 of dipole length.

Obvious negative IP responses observed in fields are frequently regarded as a failure of measurement or a kind of noise, because IP effects in rocks are defined as positive phenomena. From this study, however, it is found that obvious negative IP responses are not noise but signal in a certain situation with $\rho_1 < \rho_2$ and $PFE_1 \neq 0$. This situation may be found in an area with overburden of clay minerals. In such case, the resistivity sequence of layering is of utmost importance and should be known before planning an IP survey or attempting a quantitative interpretation of IP data.

In 1D layered model, apparent IP response (PFE_a) is obtained by a weighted sum of intrinsic IP responses (PFE_i) of each layer (seigal, 1959):

$$PFE_a = \Sigma B_i PFE_i, \tag{7}$$

where B_i are the weighting functions. Therefore, the difference between the approximate solution (Fig. 6) and the exact one (the lower figure in Fig. 5) is due to 2D effect of the resistive body ($W=4 \neq \infty$). If $W=\infty$, from (7), then the approximate solution is equivalent to the exact solution. Considering that the earth is usually more complex than the simple 2D model, and that data always have some noise, the approximate solution for $W>>t_2$ is close enough to the exact solution for geoelectric purposes.

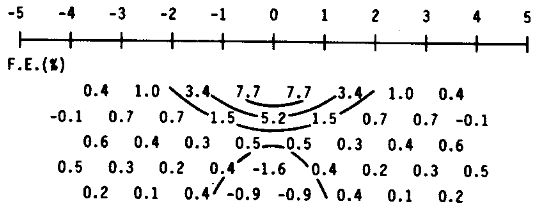

Fig. 6. IP pseudosection obtained from the superposition of the upper and middle pseudosection in Fig. 5. Contour interval is 2%.

In the numerical modeling, PFE is very useful for IP parameter, because PFE can be computed more efficiently than other IP parameters. The procedure to compute PFE introduced in this paper used to solve a kind of perturbation problem, and gives a first order solution to the perturbed problem. The first order solution is accurate enough for geoelectric purposes.

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REFERENCES

Anderson, W.L. (1979) Numerical integration of related Hankel transform of order 0 and 1 by adaptive filtering. Geophysics, v. 44, p. 1287-1305.

Bartin, J. (1968) Some aspects of induced polarization (time-domain). Geophys Prosp., v. 16, p. 401-426.

Hohmann, G.W. (1975) Three-dimensional induced polarization and electromagnetic modeling. Geophysics, v. 40, p. 309-324.

Kim, H.J. (1986) Resistivity and induced polarization modeling for arbitrary two-dimensional structures. J. Geol. Soc. Korea, v. 22, p. 366-370.

Kim, H.J. (1987) Negative induced polarization responses over a layered earth. J. Korean Inst. Mining Geol., v. 20, p. 197-201.

Nabighian, M.N. and Elliot, C.L. (1976) Negative induced-polarization effects from layered media. Geophysics, v. 41, p. 1236-1255.

Seigel, H.O. (1959) Mathematical formulation and type curves for induced polarization. Geophysics, v. 24, p. 547-565.

Snyder, D.D. (1976) A method for modeling the resistivity and IP response of two-dimensional bodies. Geophysics, v. 41, p. 997-1015.

2차원 구조에 대한 음수의 유도분극 효과

김 희 준

요약 : 2차원 구조에 대한 음수의 분도분극 반응을 차분법을 이용한 2차원 모델링 기술로 검토하였다. 유도분극 변수로서는 섭동방법으로 효율적으로 계산이 가능한 주파수 효과를 사용하였다. 전도성이면서 분극성인 얇은 표토층은 가상단면도상에서 뚜렷한 음수의 유도분극 반응을 일으킨다. 이는 분극성 표토층하에 존재하는 저항성인 부극체에 의한 반응이 단지 비저항분포의 함수만으로 음폐되는 것을 뜻한다. 그러나, 분극성 표토층하의 저항성인 비 분극체는 음수의 반응으로 발견될 수 있다.