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Technical Note TN-8

EM34-3 SURVEY INTERPRETATION TECHNIQUES

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INTRODUCTION

This technical note supplies the user of the EM34-3 with some operational information and some theoretical calculations to assist in both the planning and interpretation of geophysical surveys carried out with this instrument. It is assumed that the reader is familiar with the contents of Geonics Technical Note TN-6 which covers the general theory of terrain conductivity mapping using inductive electromagnetic techniques.

NOTES ON INSTRUMENT OPERATION

1. Coil Misalignment and Spacing Errors

It was noted in TN-6 that in the horizontal dipole mode (plane of the coils vertical) the measurement was relatively insensitive to coil misorientation: in this mode the secondary (quadraturephase) magnetic field is perpendicular to the plane of the receiver coil and a small error θ in coil misalignment produces a cos θ error in the apparent conductivity. When used in the vertical dipole mode (coil planes horizontal), however, the secondary field is approximately 45^o to the horizontal and points away from the transmitter. In this case a small error θ causes an error of the order of $\cos(\theta + 45^o)$, resulting in greater sensitivity to misalignment. The aim of the operators should be to maintain the two coils as close to coplanar as possible at all times, in either mode of operation.

It will be observed that the left-hand meter (indicating inter-coil spacing) is relatively much more sensitive to intercoil spacing than the right-hand meter, which indicates conductivity. Small variations in intercoil spacing will have no effect on the measured value of conductivity.

2. Electrical Interference

Occasionally electrical interference will be encountered, either from cultural sources (50/60 Hz power lines, industrial noise) or from atmospheric electricity (spherics). Noise from cultural sources will often manifest itself as a slow variation in the output meter reading and these variations must be averaged out by the receiver operator. The amplitude of the excursions may be a function of coil orientation and also of the intercoil spacing since the operating frequency of the EM34-3 varies with the intercoil spacing: the excursions will usually be largest at the 40m spacing. They will also of course be largest on the most sensitive (low conductivity) ranges.

In regions where intense cultural noise is suspected (near large power lines etc.) it is often a good idea to check for instrumental overloading by reducing the sensitivity by one switch position (i.e. going to the next higher conductivity range) and checking that the indicated conductivity still reads the same. To give an example: suppose we are working on the 10 mmho/m scale and the instrument reads 8 mmho/m near a power line. If the reading is not 8 mmho/m on the 30 mmho/m scale, overload is present. Suppose, however, that at the same location the instrument reads l0 mmho/m on both the 30 and the 100 mmho/m scales. Then the overload is not affecting these less sensitive ranges and they must be used in the vicinity of the interference, although the readings will necessarily be less accurate as a result of employing substantially less than full scale deflection.

Atmospheric noise will often show itself as sporadic deflections of the meter needle which are usually most severe in the horizontal dipole mode. The receiver operator must either average out the noise or else employ the vertical dipole mode of operation.

NOTES ON SURVEY INTERPRETATION

1. Linearity of Response

As stated in TN-6, at high values of terrain conductivity the indicated conductivity is no longer linearly proportional to the actual conductivity. This effect is more severe for the vertical dipole mode of operation as shown in Fig. 1 which illustrates indicated vs true ground conductivity for both operating configurations.

The curves of Fig. 1 apply to any of the three intercoil spacings. They indicate that for ground conductivity in excess of 700 mmho/m the indicated conductivity in the vertical dipole mode falls to zero, and in fact for greater conductivity it becomes negative. In those instances where the ground is known to be reasonably uniform with depth the graph can be used to approximately correct the data.

2. Relative Response with Depth

TN-6 discusses in detail the fact that it is possible to calculate the relative response from material at different depths for either operating coil configuration. The results for the EM34-3 are shown in Fig. 2 where it should be noted that the x-axis is the depth divided by the (variable) intercoil spacing. The great difference in the response to near surface material from the two coil configurations is important; the horizontal dipole mode will be relatively sensitive to variations in the near surface material whereas the vertical dipole mode will be relatively insensitive to such changes.

3. Multi-layer Calculations

The functions $R_v(z/s)$ and $R_H(z/s)$ referred to in TN-6 are illustrated in Fig. 3 which also gives their algebraic expressions. These curves, when used with the techniques outlined in TN-6, allow simple calculation of the instrument response in either coil orientation to a multi-layered (horizontally stratified) earth. It should be noted that the accuracy of this technique is greatest in regions of low conductivity and can deteriorate significantly in regions having a conductivity greater than 50 mmho/m as indicated in Fig. 1.

Using the curves of Fig. 3 it is a simple matter to calculate two-layer response curves; Figs. 4a and 4b show such curves for $\sigma_2/\sigma_1>1$ and $\sigma_2/\sigma_1<1$ respectively. It will be seen that each figure contains curves for both coil orientations since the use of the two orientations yields 6 data points with which to perform the sounding.

Assume, then, that one has six values of apparent conductivity obtained by making measurements at a site with both coil orientations at each of the three intercoil spacings. To use these curves one simply plots the measured values of apparent conductivity for both coil orientations on tracing paper to the same scale as the figure, commencing with the values for s= 40 meters, then plotting the values for s=20 meters a factor of two in distance to the right, and finally repeating the procedure for the values for s= 10 meters a further factor of two to the right. These 6 data points are then shifted horizontally and vertically until they coincide with one pair of the curves, whereupon the depth and conductivities are calculated directly, as shown in the following illustration using the measured data from Table 1.

Table 1

Apparent conductivity (mmho/m)

s(m)	Vertical Dipole	Horizontal Dipole
10	3.6	2.9
20	3.9	3.4
40	4.0	3.6

Plotting these points as described above one finds good agreement with the curve for (σ_2/σ_1)=2 when the values for s= 40 meters (4.0 and 3.6 mmho/m) are aligned at z/s =0.1; therefore z = 0.1 x 40 = 4 meters. Furthermore σ_a/σ_1 = 2 at σ_2 = 4.0 mmho/m for the vertical dipole mode; therefore σ_1 = $\sigma_a/2$ = 2.0 mmholm. Since σ_2/σ_1 = 2, σ_2 = 4.0 mmho/m and the two layer geometry is fully resolved.

A second method, kindly supplied by D. Gendzwill at the University of Saskatchewan, is as follows. Since for either coil orientation

$$\sigma_a(s) = \sigma_1 [1-R(z/s)] + \sigma_2 R(z/s) \qquad (1)$$

then

$$\sigma_a (10) = \sigma_1 + (\sigma_2-\sigma_1) R(z/10) \qquad (2)$$

$$\sigma_a (20) = \sigma_1 + (\sigma_2-\sigma_1) R(z/20)$$

$$\sigma_a (40) = \sigma_1 + (\sigma_2-\sigma_1) R(z/40)$$

from which it is easily shown that

$$\frac{\sigma_a(40)-\sigma_a(20)}{\sigma_a(20)-\sigma_a(10)} = \frac{R(z/40)-R(z/20)}{R(z/20)-R(z/10)} \qquad (3)$$

which is a single-valued function of z, and

$$\frac{\sigma_a(40)-\sigma_a(20)}{R(z/40)-R(z/20)} = \sigma_2 - \sigma_1 \qquad (4)$$

The ratio given by the left side of equation (3) is plotted as a function of z in Fig: 5. To use this figure the indicated ratio is calculated and from this ratio the graph immediately yields z in meters. R(z/40) and R(z/20) are then determined from Fig. 3 and equation (4) is used to calculate σ_2-σ_1 whence any of equations (2) are used to obtain σ_1.

For example if horizontal dipoles are used to obtain the data shown in Table 2:

Table 2

Apparent conductivity (mmho/m)

s(m)	σ_a
10	8.1
20	6.7
40	5.1

then

$$\frac{\sigma_a(40)-\sigma_a(2O)}{\sigma_a(20)-\sigma_a(10)} = \frac{5.1-6.7}{6.7-8.1} = 1.143$$

and therefore z = 10. From Fig. 3

$$R(10/40) = R(0.25) = 0.61$$
$$R(l0/20) = R(0.50) = 0.41$$

so that

$$\sigma_2 - \sigma_1 = \frac{5.1-6.7}{0.61-0.41} = -8.0$$

and

$$\sigma_1 = \sigma_a(40) - (\sigma_2-\sigma_l)\, R(z/40) = 5.1+(8 \text{ x } 0.61) = 10.0$$
$$\sigma_2 = \sigma_1 - 8.0 = 10.0 - 8.0$$

It should be noted that this method of calculating the two-layer parameters requires accurate values of apparent conductivity. In areas where the earth consists of more than two layers this calculation will often lead to an equivalent two-layered model which may prove to be useful.

4. Dike-Like Targets

When employed in the vertical dipole mode the EM34-3 operates as a quadrature-phase horizontal loop (Slingram) instrument and as such is capable of detecting dike-like targets of low conductivity-thickness product in resistive ground. To yield a characteristic horizontal loop response the target must, of course, have a thickness which is substantially less than the intercoil spacing.

Figure 6 illustrates the response from a traverse over a dike of conductivity-thickness product of 1 mho situated at a depth of 8 metres in ground of conductivity 3 mmhos/m. An intercoil spacing of 20 metres is assumed. When the EM34-3 is some distance from the dike (approximately two intercoil spacings) the instrument indicates the correct response for the homogeneous half-space. As the instrument approaches and passes over the dike the current flow in the dike becomes essentially the same as if the dike were in free space, thus giving rise to a negative going anomaly as indicated in Figure 6. Such an anomaly may be sufficiently large to make the meter reading go off-scale below zero and recent versions of the EM34-3 incorporate a meter polarity-reversal switch so that measurements can still be made. As Figure 6 indicates, the profile passes through the background value of conductivity at two locations symmetrically spaced apart by an amount s (or 20 metres in this case). This distance is a function only of the intercoil spacing and is independent of the depth to the dike.

Interpretation of such anomalies in terms of the dike conductivity-thickness product and depth is illustrated in Figure 7. To use the curves the amplitude of the anomaly is measured (in mmho/m) from the peak to the average or background level as shown in Figure 6. This amplitude, measured at two or three intercoil spacings, is plotted vertically on tracing paper to the same scale as Figure 7. The data is then shifted horizontally and vertically on the graph until a satisfactory match is achieved whereupon the depth is immediately read off. The conductivity-thickness product in mhos is calculated by taking the ratio of any of the measured conductivities to that indicated on the figure at the correct match. For example if the measured conductivities are 2.0, 1.8 and 0.8 mmho/m at 40, 20, and 10 metre intercoil spacings respectively, shifting this data on the graph shows a good match at a depth of 7 metres at which point the measured conductivity of 2 mmho/m at 40 m intercoil spacing matches with 5.5 mmho/m on the graph. The interpreted conductivity thickness is thus 2/5.5 or 0.36 mho.

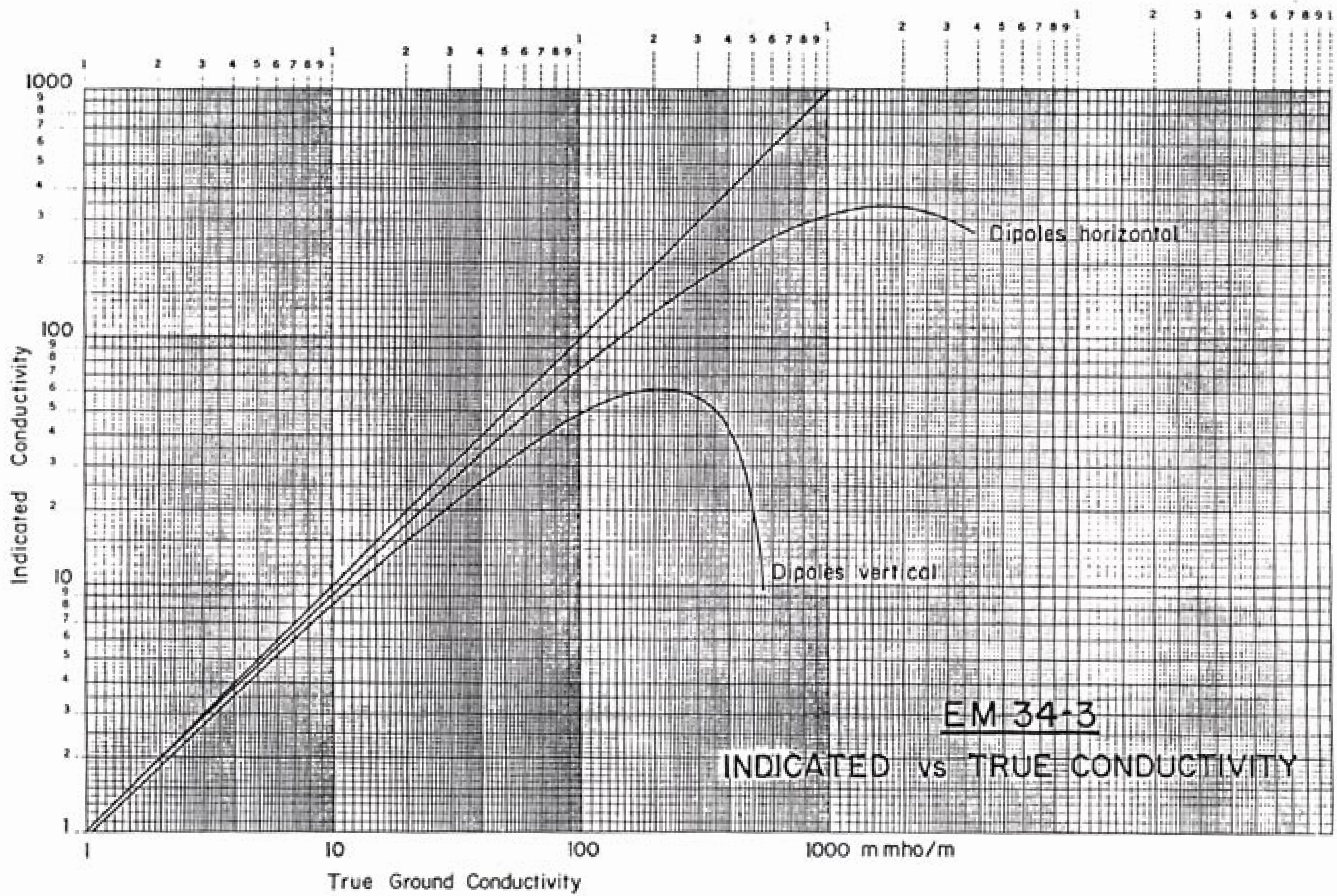
It should be noted that similar behaviour is also exhibited when a traverse is made over a dike-like target with the coils in the horizontal dipole mode - i.e. a negative going response with the same shape of Figure 6, and again the negative response may be sufficiently large to give a meter reading of less than zero. Since in general the amplitude of the response in the horizontal dipole mode is much less than that in the vertical mode the latter is recommended for quantitative analyses.

The curves of Figure 7 are valid for vertical dikes. The results are not greatly in error for dips as small as 60° but below this value the anomaly size increases and the profile shape becomes asymmetrical as shown in Figure 8 (from Nair et al*] which may be used to indicate the target dip.

CONCLUDING REMARKS

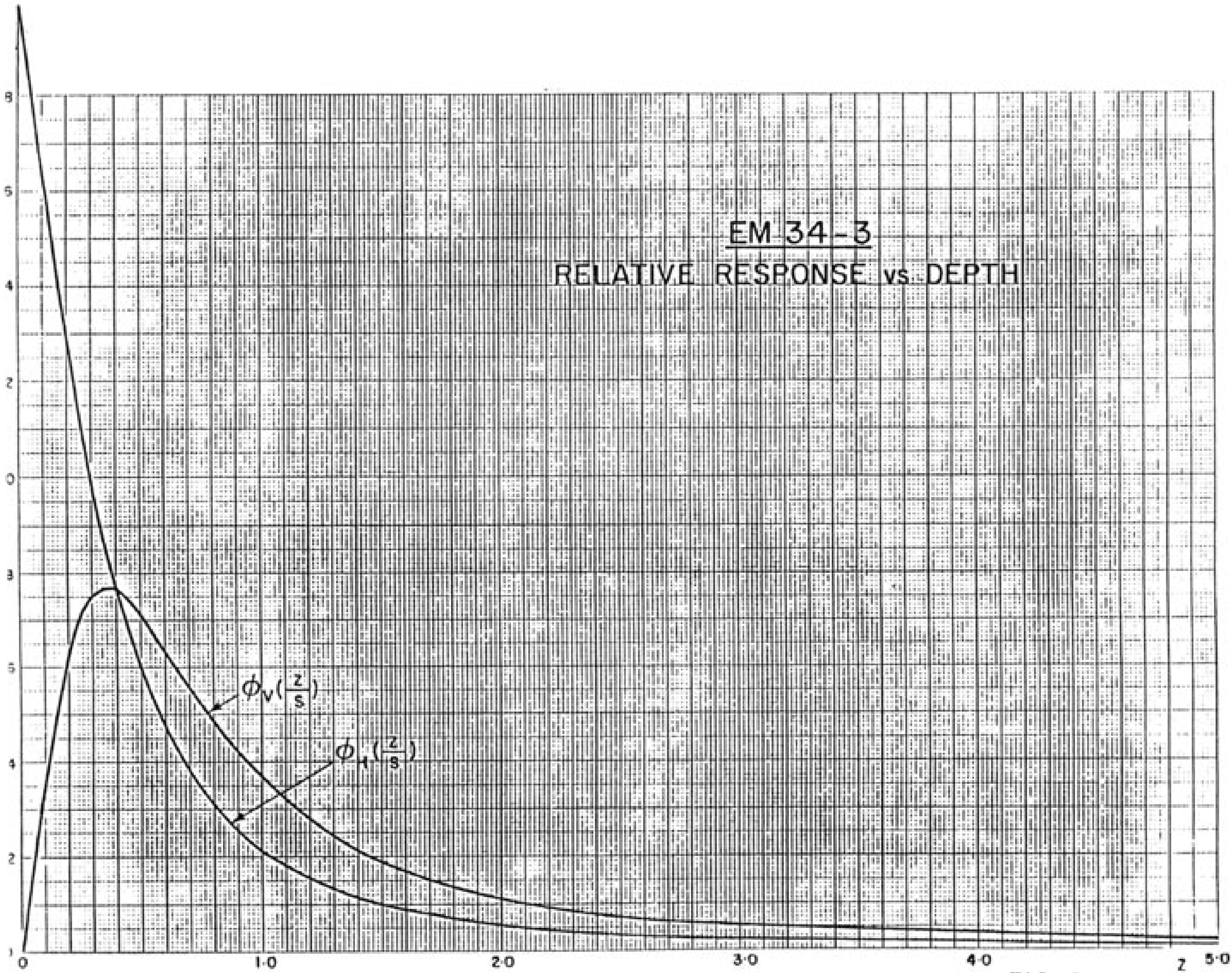
It is hoped that the material given in this technical note will assist in survey interpretation. It should be borne in mind that the strength of the EM34-3 lies in the speed with which a reconnaissance conductivity survey can be carried out to various depths of exploration. The instrument was not designed for detailed sounding of vertical variations of conductivity with depth but will give useful results where the earth can be approximated by a two-layer model. For more complicated vertical variations, conventional resistivity techniques must be used.

* Nair MR. Biswas SK, Mazumdar K. Experimental Studies on the Electromagnetic Response of Tilted Conducting Half-Planes to a horizontal-Loop Prospecting System. Geoexploration, 6 (1968) 207-244



EM 34-3
INDICATED vs TRUE CONDUCTIVITY
Dipoles horizontal
Dipoles vertical
Indicated Conductivity
True Ground Conductivity
1000 mmho/m

FIG 1



EM 34-3
RELATIVE RESPONSE vs DEPTH
$\phi_V(\frac{z}{s})$
$\phi_H(\frac{z}{s})$
0
1·0
2·0
3·0
4·0
5·0
$\frac{z}{s}$

FIG 2

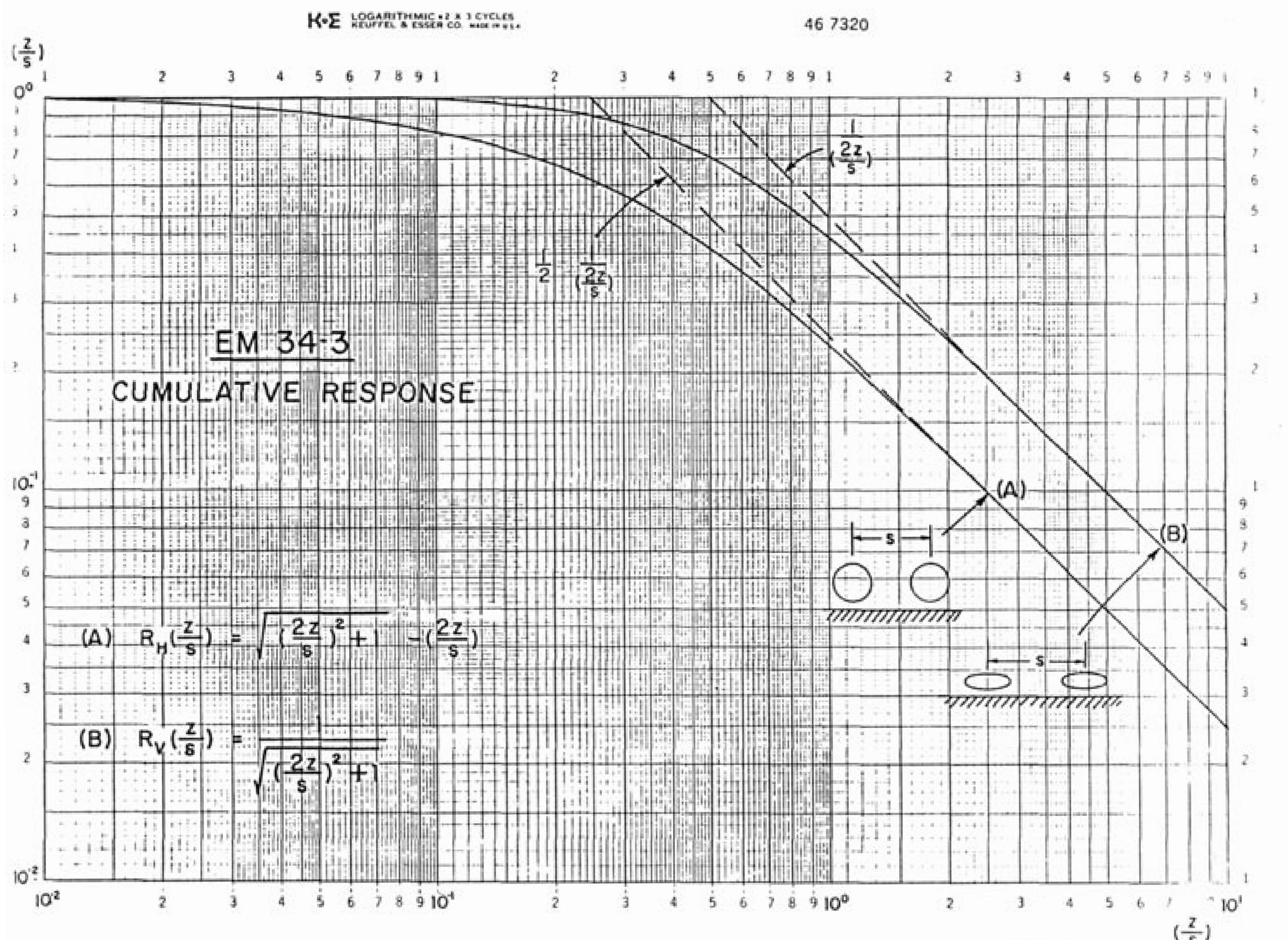
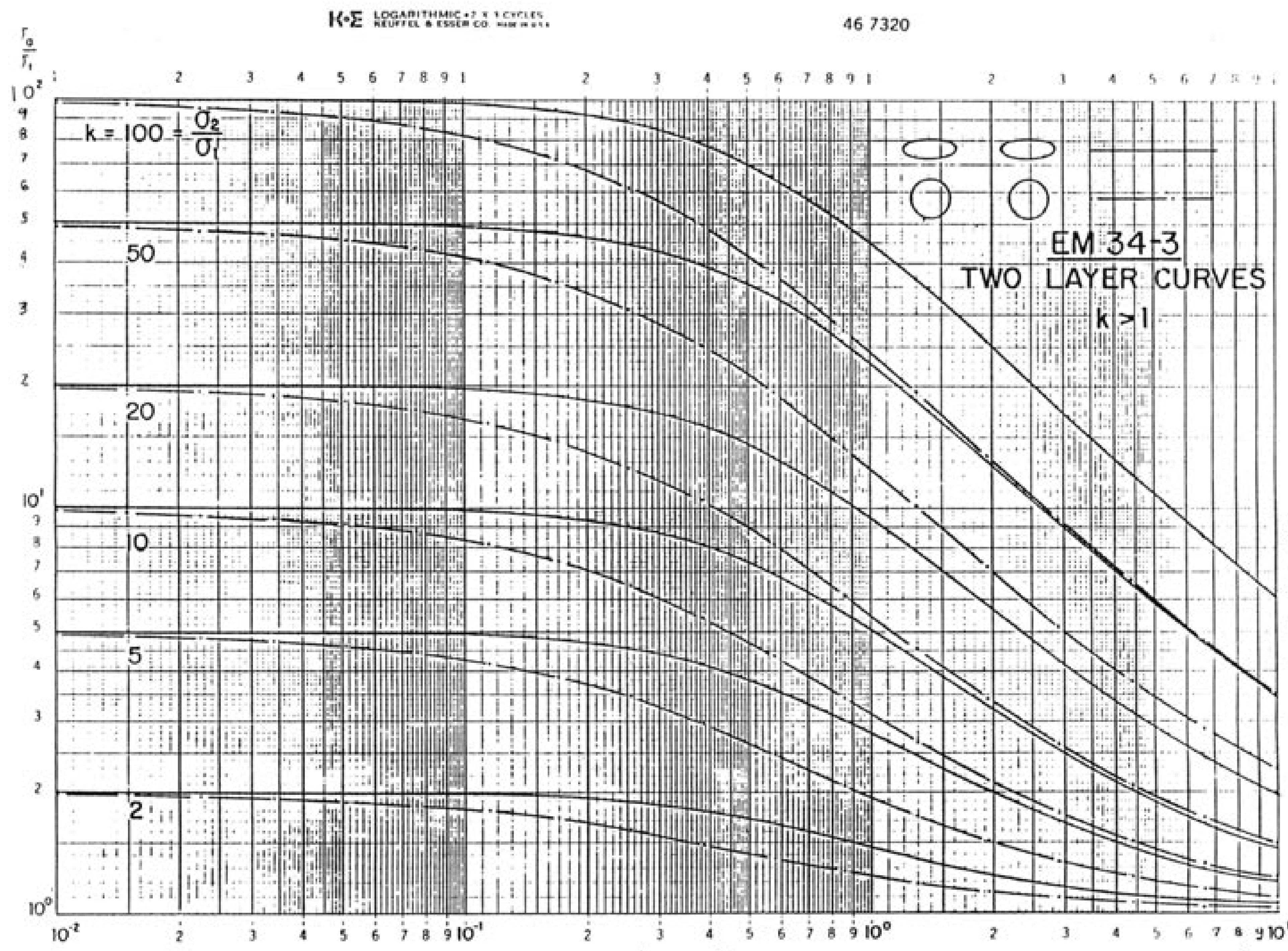
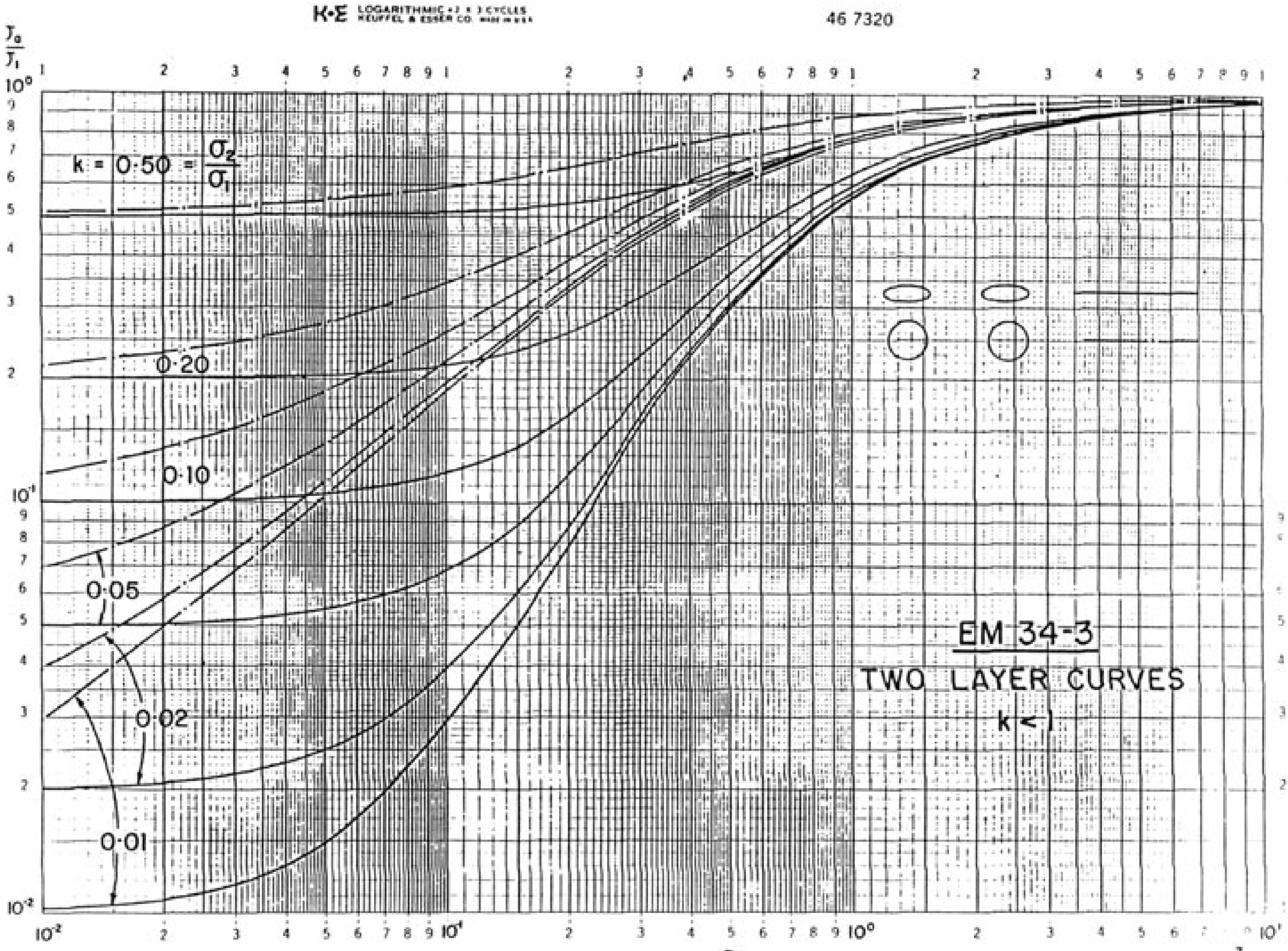

K·E LOGARITHMIC 2 X 3 CYCLES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 7320
EM 34-3
CUMULATIVE RESPONSE
(A) $R_H(\frac{z}{s}) = \sqrt{(\frac{2z}{s})^2+1} - (\frac{2z}{s})$
(B) $R_V(\frac{z}{s}) = \frac{1}{\sqrt{(\frac{2z}{s})^2+1}}$
$\frac{1}{(\frac{2z}{s})}$
$\frac{1}{2}\frac{1}{(\frac{2z}{s})}$
(A)
(B)
s
s
$(\frac{z}{s})$
10^{-2}
10^{-1}
10^{0}
10^{1}

FIG. 3



Two Layer Curves $\frac{\sigma_2}{\sigma_1} > 1$

FIG. 4a



Two Layer Curves $\frac{\sigma_2}{\sigma_1} < 1$

FIG 4b

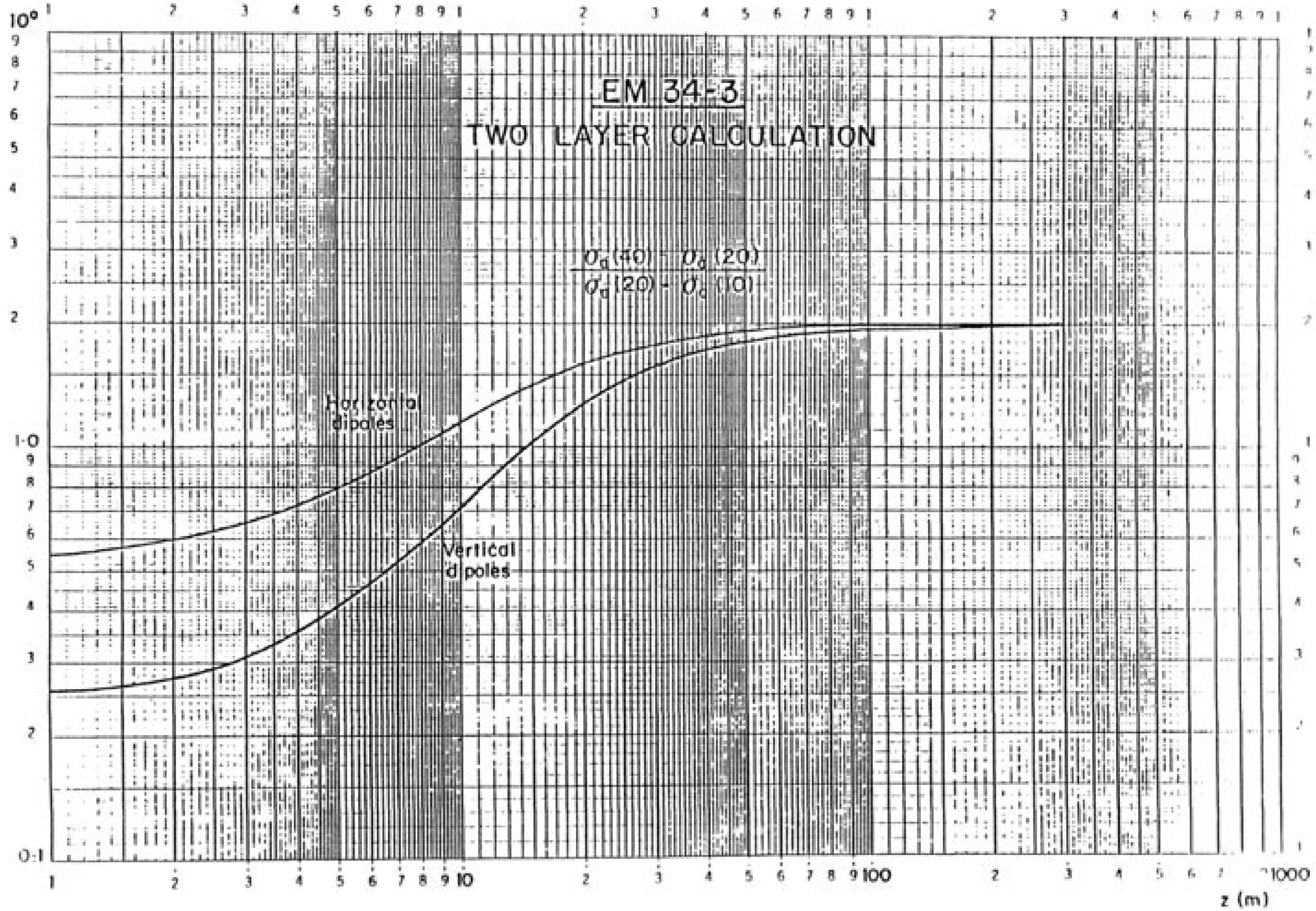

EM 34-3
TWO LAYER CALCULATION
$\frac{\sigma_a(40) - \sigma_a(20)}{\sigma_a(20) - \sigma_a(10)}$
Horizontal dipoles
Vertical dipoles
z (m)

FIG. 5

EM 34-3

VERTICAL DIKE RESPONSE

Vertical dipoles, 20meter intercoil spacing

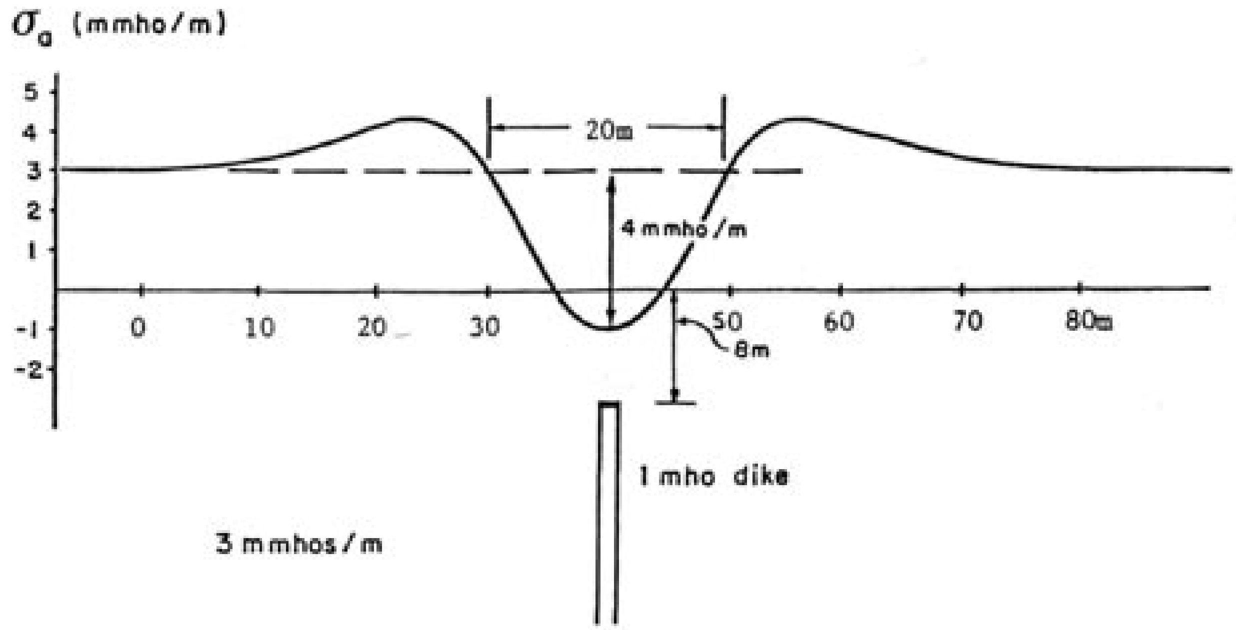
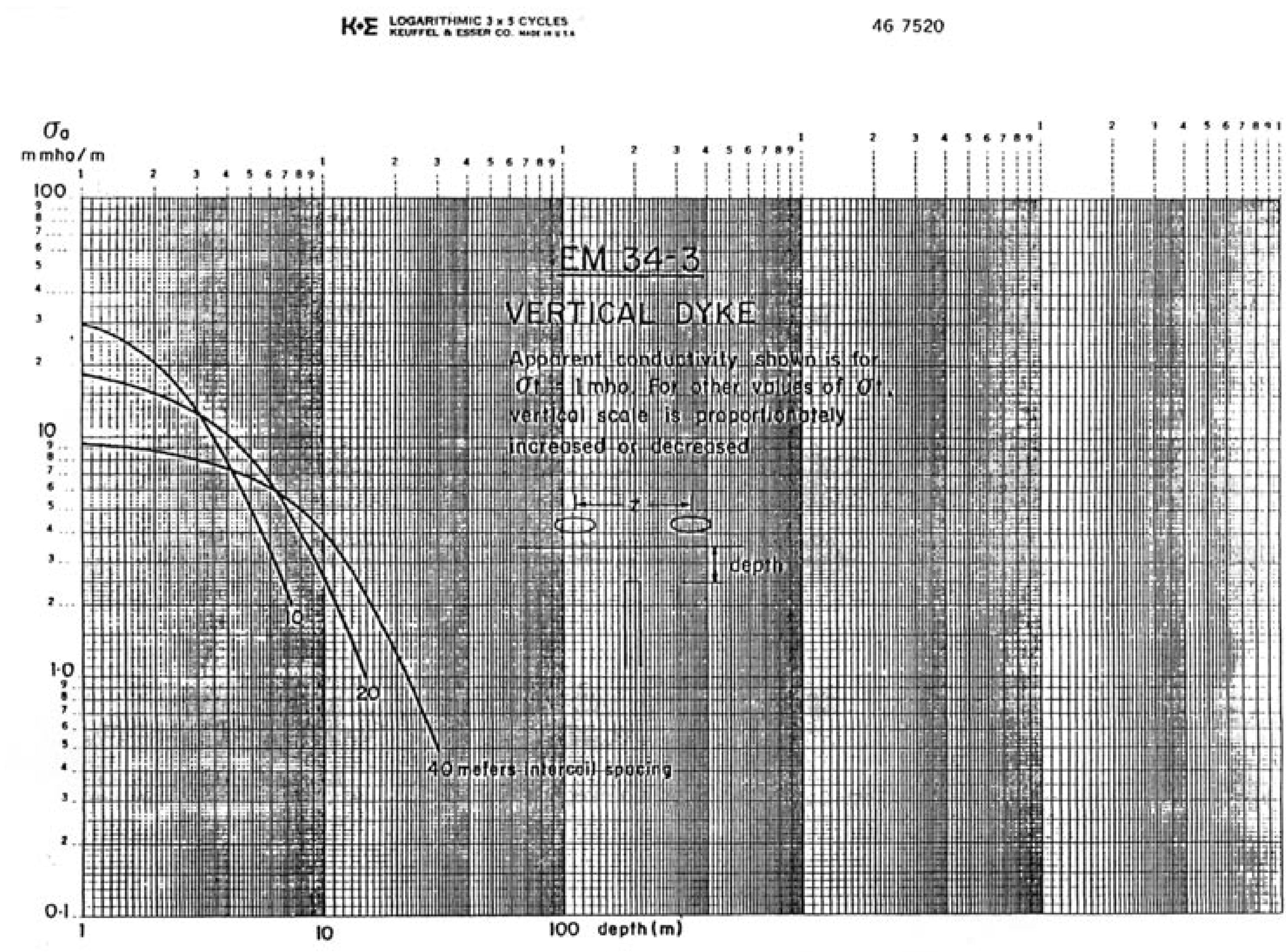


FIG. 6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46 7520
σ_a
m mho / m
100
10
1·0
0·1
1
10
100
depth (m)
EM 34-3
VERTICAL DYKE
Apparent conductivity shown is for σ_t = 1 mho. For other values of σ_t, vertical scale is proportionately increased or decreased
r
depth
10
20
40 meters intercoil spacing

FIG. 7

EM 34-3

VERTICAL DIKE

Effect of varying dip
on profile shape

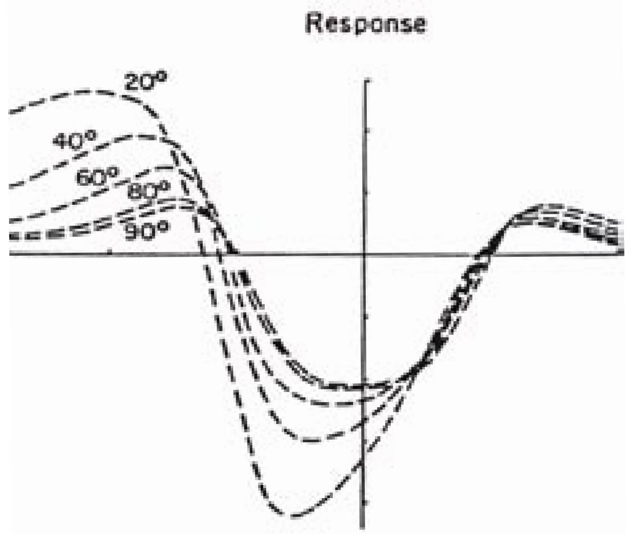

FIG. 8